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Epipelagic Fish Assemblages Associated with Juvenile Pacific Salmon in Neritic Waters of the California Current and the Alaska Current

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Abstract.—We compared epipelagic fish assemblages associated with juvenile (ocean-age 0) Pacific salmon *Oncorhynchus* spp. from neritic waters of the California Current and Alaska Current regions in the spring–summer and summer–fall periods of

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2000–2004. Catches originated from rope trawl surveys conducted between latitudes 37°N and 60°N and spanned more than 1,100 km in the coastal and inshore habitats of each region. Catch data were used from the epipelagic sampling of waters from near surface to depths of about 18 m, primarily over the continental shelf. Catch composition, frequency of occurrence, and density were evaluated between regions and habitats for day sampling. Diel (night and day) catch comparisons were also made at a few localities in each region. In day catches from both regions, a total of 1.69 million fish and squid representing 52 fish families and 118 fish species were sampled from 2,390 trawl hauls. Ninety-seven percent of the daytime catch was composed of 11 fish families and squid in coastal and inshore habitats of each region: clupeids dominated catches in the California Current (72% and 76% of catch, respectively), and salmonids dominated catches in the Alaska Current (46% and 62% of catch, respectively). Juveniles comprised 81–99% of salmon sampled in both coastal and inshore habitats of each region. Frequencies of occurrence were highest for juvenile salmon in both regions, but average densities were highest for Pacific herring *Clupea pallasii* and Pacific sardine *Sardinops sagax* in the California Current region. Cluster analyses revealed distinct geographic breakpoints in coastal species assemblages off central Vancouver Island and in inshore species assemblages in southeastern Alaska. Species were found to cluster into six groups from coastal localities and four groups from inshore localities. Indicator species analysis and nonmetric multidimensional scaling revealed that most species of juvenile salmonids were located in northern localities. Although juvenile salmon had the most uniform distribution of any species group, their densities relative to associated species were dramatically lower in the California Current, suggesting a higher degree of interactions between juvenile salmon and other species in this region. Diel comparisons in both regions indicated substantially higher catches at night, particularly of clupeids, osmerids, and gadids. Salmonids were a relatively minor component of the night catch in both regions due to dramatic diel shifts in community structure. Additional study of diel interactions of juvenile salmon and associated species is needed to quantify habitat utilization dynamics in marine ecosystems.

Introduction

Understanding the dynamics of juvenile (ocean-age 0) Pacific salmon *Oncorhynchus* spp. in marine ecosystems along the west coast of North America requires adequate information about their association with epipelagic fish assemblages in the California Current and the Alaska Current. Pacific salmon, a principal living marine resource of the eastern Pacific Ocean, comprise important components of food webs in ecosystems throughout their life history from California to Alaska and provide a significant socioeconomic and cultural benefit throughout their range (NRC 1996; Schoonmaker et al. 2003; Scheuerell and Williams 2005). In their initial ocean migration, juvenile salmon can migrate extensively across broad geographic regions and potentially interact with multiple fish communities during their first summer at sea. For example, some stocks of juvenile salmon originating from the Columbia River basin migrate as far as 1,500 km northward to Alaska shortly after their first few months at sea (Orsi and Jaenicke 1996; Orsi et al. 2000; Morris et al. 2007, this volume). Because the ocean distributions and biotic interactions of salmon are partially predetermined by their migratory routes, differences in the distribution of predators or in the structure of food chains may be important factors in the dynamics of salmon populations (Bottom et al. 2006). Additionally, most studies on the ocean survival or production of salmon point to their early ocean period as a time in which most mortality occurs (Parker 1962; Bax 1983; Pearcy 1992; Myers et al. 2000; Wertheimer and Thrower 2007, this volume). Consequently, comparing species assemblages associated with juvenile salmon during this critical period of ocean migration may provide a better understanding of how their interactions among potential prey, competitors, and predators differ between geographic regions within marine ecosystems.

The California Current (CC) and the Alaska Current (AC) are major circulation features along the west coast of North America. These currents are formed as the eastward North Pacific Current nears the west coast of North America and bifurcates into a southern (California) and a northern (Alaska) branch. These branches comprise two of three major marine fish production domains of the northeast Pacific Ocean: (1) the Coastal Upwelling Domain (southern branch) from the northern tip of Vancouver Island southward to Baja California (25–50.5°N, 110°W), and (2) the Coastal Downwelling Domain (northern branch) from Queen Charlotte Sound northward along the coast of southeastern Alaska and westward along the Aleutian Islands (51–52°N, 170°W) (Ware and McFarlane 1989). Comparisons of fish assemblages associated with juvenile salmon in epipelagic waters of the CC and AC regions may provide insight into the dynamics of these production domains.

In recent years, rope trawl surveys directed at juvenile salmon have collected large amounts of catch data in marine localities along the west coast of North America. These coast-wide surveys, both national and international in scope, have been principally conducted by researchers affiliated with the Canadian Department of Fisheries and Oceans (CDFO), the North Pacific Anadromous Fish Commission, the U.S. Global Ocean Ecosystem Dynamics (GLOBEC) Program, and the U.S. National Marine Fisheries Service (NMFS). These surveys cover broad areas in the CC and AC regions from California to Alaska. The marine focus of many of these surveys has been the epipelagic waters of the open ocean, continental shelf (neritic), and inshore localities along seaward migration corridors traversed by juvenile salmon. Associated catch data on species other than salmon from many of these surveys are often unreported, de-emphasized, or reported within a limited geographic range (Orsi et al. 2000; Brodeur et al. 2004).

The goal of this paper is to construct a comprehensive picture of the species associations and dynamics between and within the CC and AC regions by comparing fish assemblages associated with juvenile salmon over a 5-year period (2000–2004) in both spring–summer and summer–fall periods. Objectives of this paper are to compare fish communities spatially and temporally, with emphasis on catch composition, frequency of occurrence, and densities (numbers per km^2 or m^3) of juvenile salmon and principal associated fishes during day and to briefly examine diel (day and night) effects on catch.

Methods

Study Localities and Time Periods

Geographic localities and time periods in this study were selected from the available surface rope trawl catch data off the west coast of North America over the years 2000–2004. Associated fish catch data originated from multiple studies, namely regional projects directed at understanding mechanisms related to juvenile salmon survival in their estuarine and early marine life. Data from this 5-year period were compiled and partitioned into two divisions based on their association with the CC or AC regions (Table 1). Data representing the CC region were collected adjacent to the coasts of California, Oregon, Washington, and southern British Columbia, whereas data representing the AC region were collected adjacent to the coast bordering the Gulf of Alaska. These two regional divisions correspond to the Coastal Upwelling Domain and Coastal Downwelling Domain described above (Ware and McFarlane 1989).

Within both the CC and AC regions, further geographic divisions were made into coastal and inshore localities. These divisions enabled fish communities to be examined from two distinct habitats in each region based on their exposure to the open ocean. The coastal division represented localities within the northeast Pacific Ocean, including the Gulf of Alaska. The inshore division represented localities inland of the ocean margin of the coastal land mass, inclusive of the numerous straits, sounds, and large bays. These divisions were selected because inshore waters are geographically distinct and have more persistent estuarine conditions. Within these coastal and inshore divisions of each region, further geographic partitioning was done for the spatial analysis: five partitions in the CC region and two in the AC region.

Data for this study were derived from epipelagic sampling in neritic waters of the CC and AC regions. Epipelagic sampling was accomplished with rope trawls that fished the water column from near the surface to depths of about 18 m. The neritic areas sampled were on the continental shelf, generally over bottom depths averaging less than 250 m. Sampling areas also included sites with bottom depths to 500 m in cases where fjords were present, typically in inshore localities. The heads of fjords and embayments were not included in the data set because these sites were not represented in each region and because rope trawls do not effectively fish over shallow depths. Catch data without accompanying bottom depth information were not used. Thus, the scope of this study was to compare epipelagic fish assemblages in the neritic areas of the CC and AC regions, in waters over the continental shelf, and not extending into areas over abyssal or shallow embayment habitats.

From 2000 to 2004, data were pooled across years and grouped into spring–summer (SS; May to July) and summer–fall (SF; August to October) periods. The pooling of data across years was necessary because concurrent sampling did not occur within the same year or seasonal period at each regional locality. Sampling in SS and SF periods occurred in multiple years at most localities within each region, with the exception of San Francisco Bay, an inshore locality in the CC region that was sampled only in the SS period.

Data Collection and Processing the Catch

Temperature data were collected to examine regional differences by locality and season. These data were available from a portion of the trawl hauls in all areas and seasons of the study and were obtained from temperature measurements from depths of 2–4 m. Data were collected using net-mounted instruments, vessel thermosalinographs, or conductivity-temperature-depth profilers.

Catches of juvenile salmon and associated fish species and squid were sampled with several types and sizes of surface trawls in both the CC and AC regions. Surface rope trawls were fished over various bottom depths, using differing footrope depths, headrope widths, speeds, and durations. Trawling methodology was determined based on par-

Table 1. Number of years, number of surface trawl hauls, total surface area swept (SAS, km^2), and total volume sampled (TVS, m$^3 \times 10^6$) during day sampling in coastal and inshore localities of the California Current (CC) and the Alaska Current (AC) along the west coast of North America, spring–summer (May–July) and summer–fall (August–October) 2000–2004.

			Spring–summer				Summer–fall			
Current	Latitude (ºN)	Regional locality	Years	Hauls	SAS (km^2)	TVS (m^3)	Years	Hauls	SAS (km^2)	TVS (m^3)
		Coastal localities								
California	37.9	California	5	91	6.4	114.7	5	115	7.7	138.2
(CC)	44.1	Oregon	4	255	23.2	417.1	4	182	16.5	296.2
	46.7	Washington	4	136	11.5	207.6	4	81	7.5	135.3
	48.3	SW Vancouver Island	4	61	7.7	115.2	4	36	4.1	62.4
	51.0	NW Vancouver Island	2	29	4.1	45.1	5	44	6.5	77.5
		CC coastal total		572	53.0	899.7		458	42.3	709.6
Alaska	58.7	Eastern Gulf of AK	5	65	6.6	84.6	4	29	2.5	40.7
(AC)	59.1	Western Gulf of AK	3	135	18.8	261.4	4	113	10.6	168.8
		AC coastal total		200	25.4	346.0		142	13.1	209.6
		Coastal total		772	78.4	1,130.9		600	55.4	919.2
		Inshore localities								
California	37.8	San Francisco Bay	5	116	1.2	3.2	–	–	–	–
(CC)	47.7	Puget Sound	3	11	1.8	23.2	3	28	3.7	43.2
	48.4	St. of Juan de Fuca	3	24	3.8	47.5	4	38	5.9	67.7
	49.4	Strait of Georgia	3	150	22.3	266.0	4	194	28.7	340.0
	50.8	Queen Charlotte St.	2	27	3.8	44.6	4	76	10.8	141.6
		CC inshore total		328	32.9	384.5		336	49.1	592.6
Alaska	58.2	Icy Strait	5	177	7.3	132.0	5	132	6.0	108.0
(AC)	60.1	Montague Strait	3	14	0.5	9.6	3	31	1.8	31.8
		AC inshore total		191	7.8	141.6		163	7.8	139.8
		Inshore total		519	40.7	526.1		499	56.9	732.4
		All localities CC and AC		1,291	119.1	1,657.0		1,009	112.3	1,651.6

ticular sampling project goals and objectives. An example of the methodology used for surface trawling is described in Murphy et al. (1997). Specifications on average trawl dimensions and fishing performance in each region and locality are listed in Table 2.

Several criteria were used to select appropriate trawl data for this study. Establishing these criteria was necessary to adequately describe catch, to estimate surface trawl area and volume sampled, and to encompass appropriate geographic perimeters for each sampling locality. Data from hauls were used only if (1) complete enumeration and identification were done of all the fish and squid in the catch; (2) the trawl was fished with the headrope near or at the surface; (3) adequate descriptions were made of trawl headrope width, footrope depth, speed, and sampling duration; (4) bottom depth and fishing coordinates were available; and (5) data collection dates were included in the study dates (May to October 2000–2004) and were within the geographic perimeter of a sampling locality (i.e., met the spatial and temporal scheme of the study). Data not meeting any of these criteria were excluded from the analysis.

Positioning and biophysical data associated with trawling operations were compiled once the appropriate trawl data were filtered through the selection criteria. Physical data with each haul were entered into a relational database and recoded with a unique haul-catch identification number to be cross referenced with associated catch data. The core physical metrics for each trawl haul included latitude and longitude position (start or midpoint of each haul), date, time, region (CC: California, Washington, British Columbia, or AC: Alaska), primary habitat type (coastal or inshore), secondary locality within habitat type (five in CC and two in AC), trawl speed (m/s), trawl duration (s), trawl horizontal spread (m), trawl vertical spread (m), bottom depth (m), and 2–4 m temperature (and sensor depth).

Catch metrics of this study were restricted to the number and frequency of occurrence of fish species and squid. Life history stage was only consistently available across all localities in the CC and AC regions for *Oncorhynchus* spp. Salmonids were therefore subdivided into two categories for some comparisons: juvenile (fish in their first ocean year, ocean-age 0) and immature-adult (older immature and maturing fish in their second ocean year or later, ocean-age 1+). Due to the varied marine life histories of Chinook salmon *O. tshawytscha*, classification between juvenile and older immature fish was accomplished using size categories specific to each region: no attempt was made to further partition juvenile Chinook salmon into their two freshwater life history types (Healey 1983; ocean-type [freshwater-age 0] or stream-type [freshwater-age 1]). Other life history stages, when available for other genera, were grouped within species. Larval fish were not included because they were not quantitatively sampled by the relatively large mesh sizes used in the cod end liners of the trawls fished (e.g., 0.8-cm mesh). Squid were the only invertebrate species counted. In most cases, squid species were grouped together into a squid category; the only exception to this was for market squid (also known as opalescent inshore squid) *Loligo opalescens* where consistent reporting enabled analysis at the species level. Gelatinous species (i.e., ctenophores and cnidarians) were not included because of inconsistent record keeping and identification among data sets. Other incidental nekton catches, such as marine mammals and seabirds, were likewise not quantified. Size (weight or length) information was not consistently available across localities and regions for individual species, so biomass could not be calculated.

Table 2. Average bottom depths and surface trawl sampling characteristics in the coastal and inshore localities of the California Current (CC) and the Alaska Current (AC) along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004.

Current	Regional locality	Latitude (ºN)	Period	Sea floor depth (m)	Foot rope depth (m)	Head rope width (m)	Rope trawl speed (m/s)	Haul fishing time (min)	Surface area swept (km^2)	Total volume sampled ($m^3 \times 10^6$)
			Coastal localities							
California (CC)	California	37.88	SS	50	18	30	1.77	23	0.075	1.33
		37.91	SF	60	18	30	1.74	23	0.075	1.35
	Oregon	44.02	SS	114	18	30	1.68	30	0.090	1.63
		44.15	SF	117	18	30	1.73	29	0.091	1.64
	Washington	46.71	SS	88	18	30	1.74	27	0.086	1.55
		46.77	SF	83	18	30	1.77	30	0.094	1.70
	SW Vancouver Island	48.34	SS	87	15	32	2.25	29	0.128	1.89
		48.17	SF	85	15	31	2.15	29	0.118	1.73
	NW Vancouver Island	51.24	SS	127	11	33	2.45	30	0.144	1.58
		50.89	SF	86	13	31	2.61	30	0.147	1.84
Alaska (AC)	Eastern Gulf of AK	58.68	SS	134	14	35	1.96	25	0.123	1.45
		58.63	SF	132	17	34	1.94	26	0.116	1.85
	Western Gulf of AK	59.07	SS	182	14	40	2.13	29	0.158	2.14
		59.02	SF	167	16	35	1.82	30	0.120	1.79
			Inshore localities							
California (CC)	San Francisco Bay	37.83	SS	40	3	6	1.12	23	0.011	0.03
	Puget Sound	47.70	SS	123	13	34	2.61	30	0.160	2.06
		47.71	SF	130	12	33	2.29	30	0.133	1.56
	St. of Juan de Fuca	48.33	SS	91	12	33	2.63	30	0.156	1.92
		48.37	SF	79	11	33	2.70	30	0.157	1.79
	Strait of Georgia	49.45	SS	203	12	33	2.53	30	0.149	1.78
		49.36	SF	190	12	32	2.54	30	0.147	1.75
	Queen Charlotte Strait	50.76	SS	181	12	32	2.47	30	0.141	1.63
		50.76	SF	165	13	32	2.49	30	0.143	1.88
Alaska (AC)	Icy Strait	58.20	SS	218	18	24	1.44	20	0.041	0.75
		58.21	SF	209	18	24	1.44	22	0.046	0.83
	Montague Strait	60.13	SS	268	18	24	1.44	20	0.040	0.73
		60.12	SF	268	18	24	1.44	27	0.056	1.01

Data Analysis

Catch in number and frequency of occurrence were examined from the trawl catch data from each region. Initially, predominant fish families and squid were summarized by region (CC and AC) and habitat (coastal and inshore). Catch of juveniles of each salmon species was calculated by region, habitat, and time period (SS and SF). To examine spatial differences in juvenile salmon catch, the percentage represented by juvenile salmon and other dominant species was examined by the seven regional localities in both coastal and inshore waters. Frequency of occurrence for juvenile salmon and other important species was calculated by region, habitat, and time period.

For regional comparisons of catch density, catches were standardized to the numbers of fish or squid captured per amount of surface area swept (SAS) or total volume sampled (TVS). The SAS (km^2) was estimated for each haul by multiplying the trawl speed (T_{sp} in m/s) by the duration fished (D_f in s) and the headrope width (HR_w in m), and dividing the sum by 10^6 (m^2/km^2) so that SAS = ($T_{sp} \times D_f \times HR_w$) $\times 10^{-6}$. The TVS (m^3) was estimated for each haul by multiplying the trawl speed (T_{sp}) by the duration fished (D_f), the headrope width (HR_w), and the footrope depth (FR_d in m) so that TVS = $T_{sp} \times D_f \times HR_w \times FR_d$. Average T_{sp} over the course of a haul was obtained from a current meter, an acoustic Doppler current profiler, or a global positioning system. For hauls where T_{sp} was not available, average speed was estimated from previous trawl hauls or determined from average values over the course of sampling where trawl speed was measured. Generally, average T_{sp} ranged from 1.1 to 2.6 m/s. Variation in T_{sp} between trawls was not assumed to affect catchability or catch composition. The D_f was the time between when the trawl and doors were deployed in full fishing position and the time when the winches began to haul back the main warp lines. Average D_f was 20–30 min. Catches were assumed to be negligible during deployment and retrieval. The HR_w was the spread between the wing tips along the headrope of the trawl and was either recorded with mensuration gear onboard or estimated from previous trawl performance data. Generally, average HR_w was 24–40 m. The FR_d was the depth between the headrope and the footrope of the trawl and was determined the same way HR_w was. Generally, average FR_d was 11–18 m. A smaller surface trawl was used to collect data from one locality and season in the CC (San Francisco Bay in the SS period); the dimensions of this trawl were HR_w = 6.0 m and FR_d = 3.1 m. Catchability was assumed to be similar among vessels and trawls used to summarize fish assemblages.

Most sampling was during daytime hours, but a limited set of night hauls was available to compare with day hauls to determine possible diel (day and night) differences. Daytime sampling was between 0630 and 2130 hours, whereas night sampling was between 2140 and 0500 hours Diel comparisons were accomplished by matching data sets with diel sampling at the same locality, with the same vessel, and within approximately the same 24-h time period. Only matched day and night sampling sets with two or more hauls per 24-h period were used in these comparisons (i.e., six data sets, two in the CC region and four in the AC region).

For diel comparisons in the CC region, two coastal localities were examined for differences in catch composition, one in summer of 2002 and another in fall of 2002. The summer diel sampling was conducted on the Newport Hydroline transect (44.650°N, 124.182°W) in June, whereas, the fall diel sampling was conducted on the Heceta Head transect (44.000°N, 124.399°W) in August.

For diel comparisons in the AC region,

one coastal locality and one inshore locality were examined. The coastal locality was examined using data collected on the GAK transect line in the western Gulf of Alaska in July 2001 (59.536°N, 149.170°W) and 2002 (59.699°N, 149.330°W). The inshore locality was examined using data collected on the Icy Strait transect line (station ISC; 58.260°N, 135.440°W) in June–July and August–September 2001.

Community Analyses

To analyze the epipelagic nekton community structure, we performed cluster analysis, indicator species analysis (Dufrêne and Legendre 1997), and nonmetric multidimensional scaling (NMS; Kruskal 1964) using PC-ORD version 4.28 software[1] (McCune and Mefford 1999). Prior to analysis of sample units in species space, hauls with no catches were removed from the data set. Catch density data (catch × m^{-3}) were $\log_{10}(x + 1)$-transformed to normalize a strongly skewed distribution.

An agglomerative hierarchical cluster analysis with Sørensen (Bray-Curtis) distance measure and flexible beta linkage method ($\beta = -0.25$) was conducted on species abundances. Two sets of cluster analyses were performed. The first, conducted to examine which localities resemble each other in terms of their species composition, examined a localities-by-species matrix of all species for each seasonal period (SS and SF) and habitat (coastal and inshore) for a total of four matrices (Table 3). Because some species have a northern or southern distribution, all species were included in this set of analysis so that localities with similar species composition would cluster together. Species abundances were averaged for each locality. The second set of cluster analyses examined a species-by-hauls matrix for each seasonal period and habitat (Table 3). To reduce the effects of rare species and to use species common to all localities for comparison between regions, species with a frequency of occurrence of less than 5% of hauls were removed. In the SS period and coastal habitat, unidentified rockfish *Sebastes* spp. had a frequency of occurrence of greater than 5%; however, they were excluded because other rockfish that were identified to species had a frequency of occurrence of less than 5%. For subsequent multivariate analysis that examined the nekton community and complementary environmental data, only hauls with temperature

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 3. Sizes of matrices used in the multivariate analyses of region and species assemblages in the coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004.

Cluster	Time period	Habitat	Matrix
Locality	SS	Coastal	7 localities × 103 species
	SF	Coastal	7 localities × 95 species
	SS	Inshore	7 localities × 77 species
	SF	Inshore	6 localities × 51 species
Species	SS	Coastal	24 species × 647 hauls
	SF	Coastal	24 species × 488 hauls
	SS	Inshore	21 species × 455 hauls
	SF	Inshore	16 species × 403 hauls

data were used. In community analysis, relativization is recommended to equalize variables with different units by expressing them as a proportion of totals or maximum (McCune and Grace 2002). Because trawl speed, duration fished, and trawl mouth dimensions affect catches, the log-transformed abundance data were relativized by species totals across all hauls to equalize species abundance among hauls. The final matrices express species abundance in a haul proportional to the total catch of this species in all hauls. The resulting dendrograms were cut to identify cluster groups that are ecologically interpretable for the current systems and localities being examined and for the life habits of species.

Indicator species analysis was run to identify which species best represent a locality. For each species, indicator values (IV) were computed for each locality by calculating the proportion of its abundance in a locality relative to its total abundance at all localities and the proportion of its frequency of occurrence in a locality relative to its total frequency of occurrence at all localities. The IV ranged from 0% to 100%, and a species observed in all hauls within a locality had an IV of 100%. A species maximum IV (IV_{max}) and the locality where this occurred were identified. To test the statistical significance of IV_{max}, a Monte Carlo randomization with 1,000 runs was performed.

Nonmetric multidimensional scaling was chosen as the ordination technique to further examine the community structure and relate it to environmental gradients. Distances between points were computed with a Sørensen (Bray-Curtis) distance measure. For this analysis, transposed versions of the species-by-hauls matrices used in cluster analysis formed the main matrices. Abundances were not relativized. Temperature (°C), bottom depth (m), and latitude (decimal degree) were the variables used in complementary environmental data matrices. Initially, NMS was processed through 400 maximum iterations, 40 real runs, and 50 randomized runs (McCune and Grace 2002). The decrease in stress with the addition of each ordination axis was examined, and selection of a three-dimensional solution was based upon stress reductions becoming small (Legendre and Legendre 1998; McCune and Grace 2002). This dimension is appropriate for explaining variation in the original data. The final ordination was then generated on that dimension and the best starting configuration. The ordination axes were rotated to maximize the correlation of latitude with one of the axes. In addition, environmental variables were overlaid as vectors on the ordination plots. The strength and direction of the vectors were determined by Pearson and Kendall correlations. To explain the percent of variation in the original multidimensional space, coefficients of determination (r^2) were computed for each axis.

Results

Environmental Variables

Temperature at 2–4 m was available from 89% of the trawl hauls for a total 2,116 temperature records (Table 4). Over the course of the study, temperature averages ranged from 9.5°C to 15.6°C, and were warmest and most variable in inshore localities of the CC and coolest in the inshore localities of the AC. For coastal localities, SS and SF temperatures averaged 12.2°C and 12.0°C in the CC and 12.8°C and 13.3°C in the AC. For inshore localities, SS and SF temperatures averaged 14.4°C and 12.1°C in the CC, and 12.2°C and 11.6°C in the AC.

Catch Data

In both current systems combined, neritic fish assemblages were examined from a total of 1,372 hauls from coastal sampling and 1,018 hauls from inshore sampling (Table 1). The approximate along-shelf distribution of hauls in each region spanned more than 1,400 km in the CC and more than 1,100 km in the AC

Table 4. Average temperature readings and standard error (SE) associated with surface trawl hauls fished during day in coastal and inshore localities of the California Current (CC) and the Alaska Current (AC) along the west coast of North America, spring–summer (May–July) and summer–fall (August–October) 2000–2004. Average depths of temperature readings are shown under the Depth column.

		Spring–summer			Summer–fall		
Current	Regional locality	*N*	Temp (SE)	Depth	*N*	Temp (SE)	Depth
	Coastal localities						
California (CC)	California	90	12.4 (0.5)	4.0	111	13.2 (0.4)	4.0
	Oregon	247	11.9 (0.5)	3.0	177	10.8 (0.5)	3.0
	Washington	127	12.9 (0.4)	3.0	80	13.4 (0.4)	3.0
	SW Vancouver Island	60	11.9 (0.4)	3.6	33	11.8 (0.5)	3.4
	NW Vancouver Island	17	10.2 (0.4)	4.0	27	10.9 (0.3)	3.4
	CC average	541	12.2 (0.1)	3.3	428	12.0 (0.1)	3.3
Alaska (AC)	Eastern Gulf of AK	64	12.6 (0.5)	4.0	29	13.3 (0.7)	4.0
	Western Gulf of AK	117	13.0 (0.4)	2.0	70	13.3 (0.4)	2.0
	AC average	181	12.8 (0.1)	3.2	99	13.3 (0.2)	2.7
	Inshore localities						
California (CC)	San Francisco Bay	103	14.2 (0.3)	4.0	–	–	–
	Puget Sound	11	13.0 (0.3)	4.0	26	12.8 (0.2)	4.0
	St. of Juan de Fuca	24	10.6 (0.2)	4.0	38	9.8 (0.2)	4.0
	Strait of Georgia	133	15.6 (0.6)	4.0	182	12.7 (0.4)	4.0
	Queen Charlotte Strait	5	9.8 (0.1)	4.0	19	9.5 (0.2)	4.0
	CC average	276	14.4 (0.1)	4.0	265	12.1 (0.1)	4.0
Alaska (AC)	Icy Strait	175	12.2 (0.5)	4.0	132	11.4 (0.6)	4.0
	Montague Strait	10	13.6 (0.4)	2.0	9	14.4 (0.1)	2.0
	AC average	185	12.2 (0.1)	3.9	141	11.6 (0.2)	3.9

(Figures 1 and 2). A distance of 850 km separated the sampling localities in these two regions. In daytime catches in both regions, a total of 1.69 million fish and squid representing 52 fish families and 118 fish species were collected from the 2,390 trawl hauls (231 km^2 surface area swept and 3.3 $\times$ 10^9 m^3 volume fished) (Table 5; Appendix A). Eleven fish families and squid comprised 97% of the day catch in the coastal and inshore habitats of each region. Predominant families in the total catch of coastal and inshore localities of each region were Clupeidae in the CC (72% and 76% of catch, respectively) and Salmonidae in the AC (46% and 62% of catch, respectively) (Figure 3).

Juvenile salmon represented 81–99% of the salmonid catch in inshore and coastal localities of the CC and the AC regions in the SS and SF periods (Table 6). However, in terms of percentage of the total catch, juvenile salmon collectively comprised a much lower percentage of the overall catch in the CC region (2–13%) compared to the AC region (35–83%). When examined by regional locality, the percentage composition of juvenile salmon relative to other species was lowest in coastal localities, particularly in the CC (Figure 4).

Frequency of occurrence (FO) was greater than 10% of the catch for 25 fish species and 1 squid species in SS or SF periods in the CC and AC regions (Table 7). A prominent spatial and temporal pattern in both regions was the universally high FO for all five species of juvenile salmon (Figure 5). Juvenile Chinook salmon FO was highest in inshore localities of both regions, but higher in the CC region than the AC region. The FOs for other salmonids were generally highest in the AC region.

Highest average fish densities were observed for Pacific herring *Clupea pallasii*, Pacific sardine *Sardinops sagax*, and northern anchovy *Engraulis mordax* in the CC region (Tables 8 and 9). Densities for these species exceed 1,000 fish/km^2 and 200 fish/m^3 $\times$ 10^6 in one or more seasonal periods in the CC region. However, the proportion of juvenile salmon densities relative to associated species was dramatically lower in the CC region than in the AC region. Most species of juvenile salmon had higher average densities in the AC region, particularly pink salmon *O. gorbuscha*, chum salmon *O. keta*, and sockeye salmon *O. nerka*; however, densities of Chinook salmon were higher in the CC region (Figures 6 and 7).

Diel comparisons of community structure indicated dramatic changes between day and night catches in both the CC and the AC regions (Tables 10–12). All six comparisons indicated substantially higher total catches at night, in most cases by an order of magnitude (Figure 8). Higher night catches were particularly evident with clupeids, gadids, and osmerids. There was not a consistent day and night pattern of catches for salmonids, although for juvenile salmon, there was a tendency for higher night catches in the CC region and higher day catches in the AC region (Figure 8).

Community Analyses

To identify ecologically interpretable cluster groups, the locality cluster dendrograms were cut at 25% of information. This produced two cluster groups in all four dendrograms (Figures 9–12). In the coastal habitat, the group separation was between northwestern and southwestern Vancouver Island for both time periods (Figures 9 and 10). In the inshore habitat, the cluster group separation was between Icy Strait and Queen Charlotte Strait (Figures 11 and 12).

The species cluster dendrograms were cut at 35% and 30% of information remaining for the coastal and inshore habitats, respectively. In the coastal habitat, the 35% cutoff resulted in six cluster groups (A to F) for the SS and SF periods (Figures 13 and

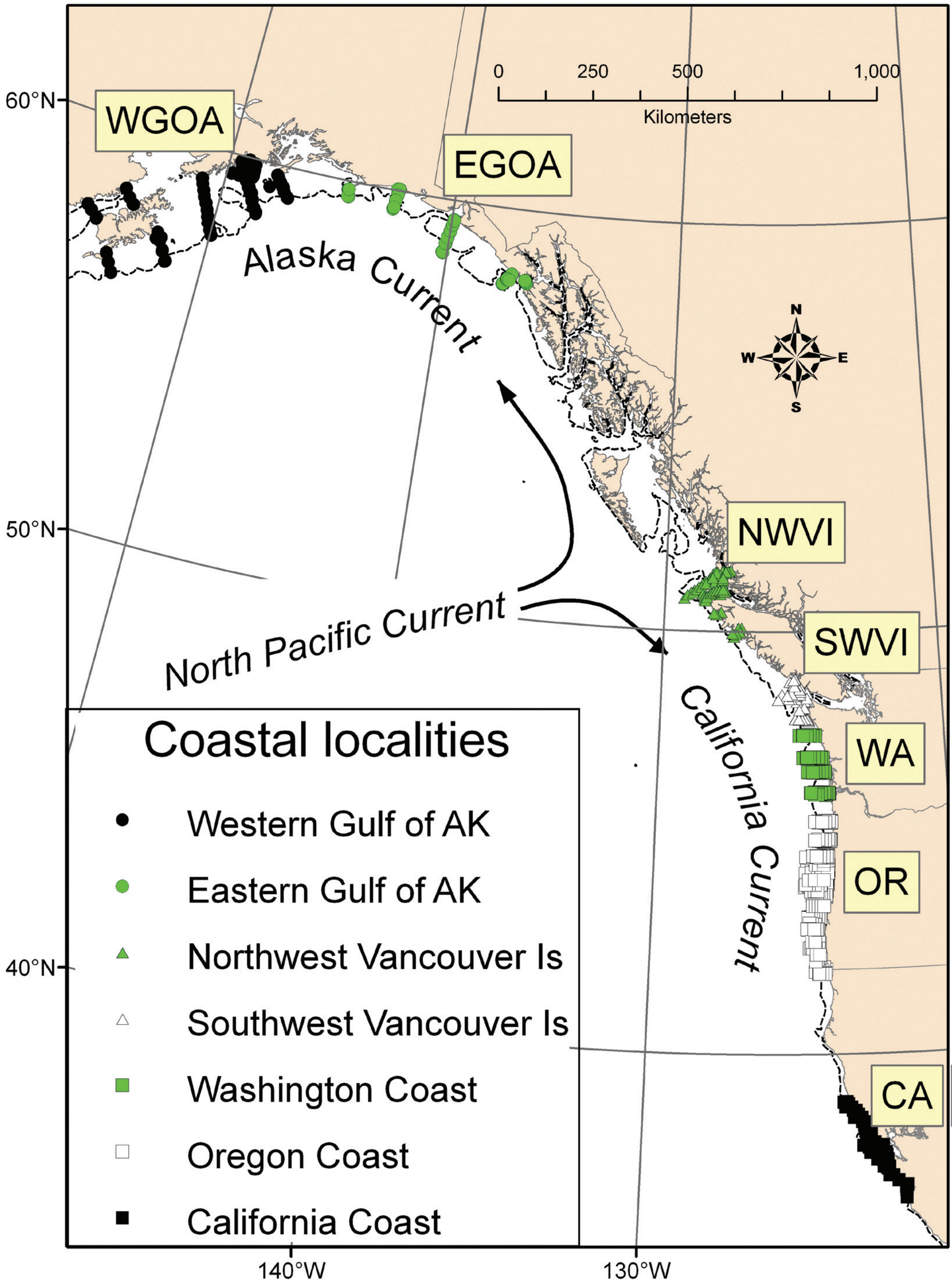


Figure 1. Coastal localities sampled for epipelagic fish and squid using surface trawls in the neritic waters of the California Current (northwest Vancouver Island and south) and the Alaska Current (eastern Gulf of Alaska and north) during daylight hours, May–October 2000–2004. Dotted line denotes the 200-m depth contour of the continental shelf margin.

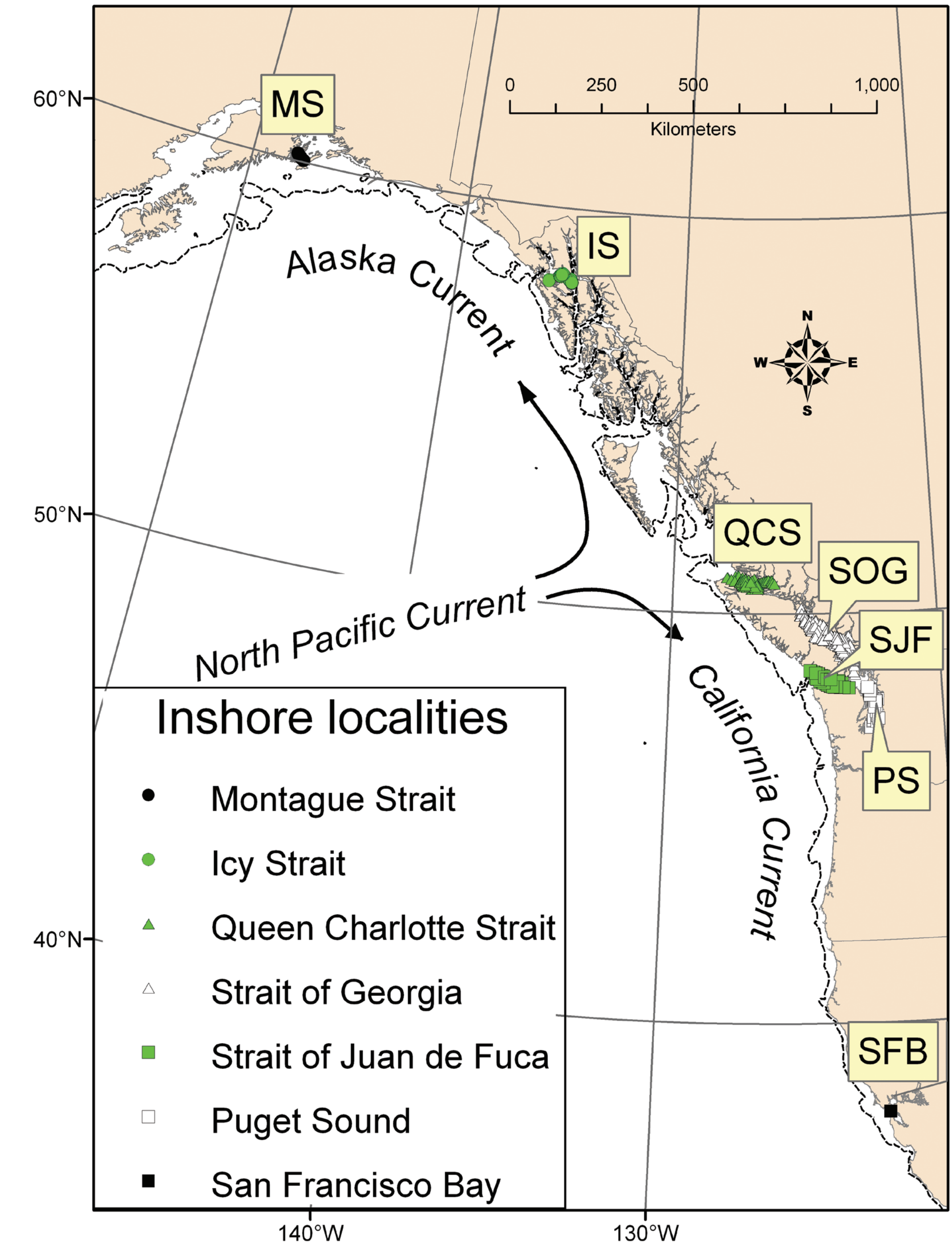


Figure 2. Inshore localities sampled for epipelagic fish and squid using surface trawls in the neritic waters of the California Current (Queen Charlotte Strait and south) and the Alaska Current (Icy Strait and north) during daylight hours, May–October 2000–2004. Dotted line denotes the 200-m depth contour of the continental shelf margin.

Table 5. Total day catches of neritic fishes and squid by family group using surface trawls in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Family	SS	SF	SS	SF	SS	SF	SS	SF
Agonidae	3	31	350	6	0	1	0	2
Alopiidae	3	5	0	0	0	0	0	0
Ammodytidae	658	4	237	1,105	410	1,824	1	0
Anarhichadidae	75	36	129	10	7	5	9	5
Anoplopomatidae	744	63	28	0	137	162	0	0
Atherinidae	6,428	9,533	612	0	0	0	0	0
Batrachoididae	1	2	2	2	0	0	0	0
Bothidae	134	53	0	0	0	0	0	0
Bramidae	0	0	0	0	7	26	0	0
Carangidae	1,193	1,231	0	0	0	0	0	0
Carcharhinidae	62	32	0	0	0	0	0	0
Centrolophidae	66	328	0	0	0	0	0	0
Chimaeridae	0	0	0	1	0	0	0	0
Clupeidae	281,628	225,608	386,126	266,256	216	4,182	135	70
Cottidae	18	3	7	0	0	0	0	0
Cyclopteridae	0	1	0	9	15	6	16	14
Embiotocidae	0	10	77	0	0	0	0	0
Engraulidae	70,660	15,680	59,102	11	0	0	0	0
Gadidae	834	106	51	41	1,918	1,732	4,631	12,153
Gasterosteidae	1	12	381	30,124	3	5,001	0	0
Hemitripteridae	1	0	3	0	8	19	205	232
Hexagrammidae	150	2	118	3	193	1	1	1
Icosteidae	1	6	0	0	0	0	0	0
Lamnidae	0	1	0	0	4	6	4	3
Liparidae	1	0	0	6	1	0	0	0
Merlucciidae	109	11	97	211	0	0	0	1
Molidae	28	36	0	0	0	0	0	0
Myctophidae	0	2	0	0	0	0	0	0

Table 5. Continued.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Family	SS	SF	SS	SF	SS	SF	SS	SF
Myliobatidae	3	3	16	0	0	0	0	0
Myxinidae	0	0	17	0	0	0	0	0
Osmeridae	11,173	2,974	16	161	3,158	4,637	3	89
Petromyzontidae	4	2	478	59	0	1	0	0
Pholidae	0	0	0	1	0	0	0	0
Pleuronectidae	53	30	40	12	4	1	1	0
Psychrolutidae	3	0	10	0	6	37	7	1,083
Ptilichthyidae	0	0	21	3	0	0	0	0
Rajidae	3	6	0	0	0	0	0	0
Rhamphocottidae	0	0	0	0	0	1	0	0
Salmonidae	10,811	5,983	64,911	43,691	19,246	15,786	26,824	4,400
Sciaenidae	61	77	1	0	0	0	0	0
Scomberesocidae	122	2,477	0	0	0	9	0	0
Scombridae	70	105	0	0	0	0	0	0
Scorpaenidae	2473	45	22	4	54	8	1	0
Sphyraenidae	0	1	0	0	0	0	0	0
Squalidae	9,998	1,442	2,927	1,692	7,289	561	0	0
Squid	21,983	23,010	1,324	270	577	202	1	9
Stromateidae	250	261	963	0	0	0	0	0
Syngnathidae	0	0	11	69	0	0	0	0
Torpedinidae	7	7	2	0	0	0	0	0
Trachipteridae	1	10	0	0	0	0	0	0
Triakidae	26	1	0	0	0	0	0	0
Trichodontidae	44	3	33	8	74	8,076	9	2
Zaproridae	7	4	0	0	130	62	59	44
Grand total	419,890	289,237	518,112	343,755	33,457	42,346	31,907	18,108
Fish family total (52 total families)	40	42	30	23	20	23	15	14

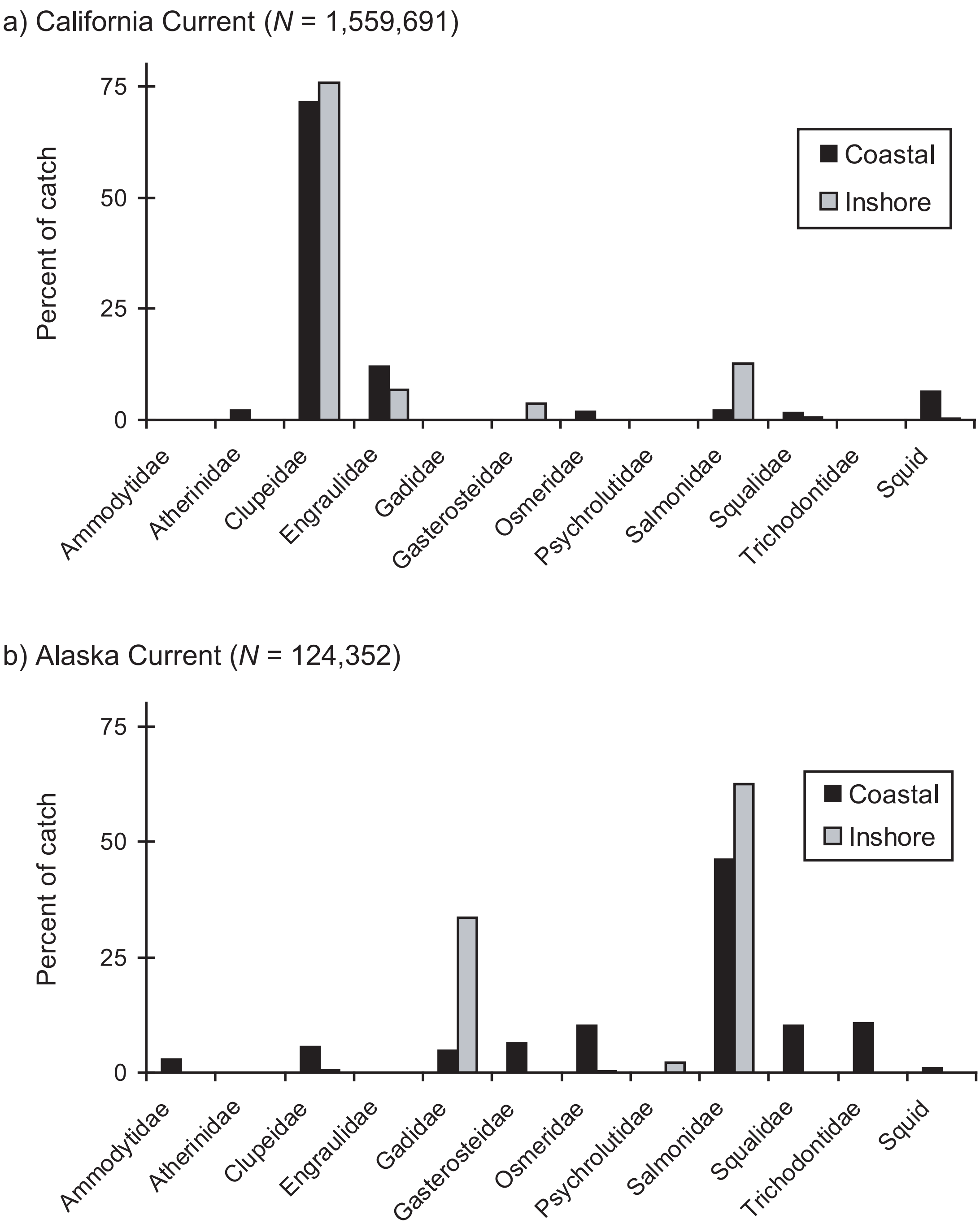


Figure 3. Principal composition of epipelagic fish families and squid captured in the California Current (a) and the Alaska Current (b) using surface trawls in neritic coastal and inshore waters along the west coast of North America during daylight hours, May–October 2000–2004. The 11 fish families and squid represent 97% of the total catch in each current system.

Table 6. Percentage of catch represented by juvenile and immature-adult salmon species from day catches of neritic fishes and squid sampled in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. A dash indicates an absence of catch.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Species	SS	SF	SS	SF	SS	SF	SS	SF
Juvenile salmon								
Pink salmon	0.2	0.5	2.8	2.7	29.5	17.3	38.7	14.2
Chum salmon	0.4	0.1	5.1	5.5	9.9	5.6	36.0	4.7
Sockeye salmon	0.2	0.1	0.3	0.8	5.9	8.9	4.3	2.0
Coho salmon *O. kisutch*	0.6	0.6	2.4	2.0	4.5	3.2	4.1	1.9
Chinook salmon	0.7	0.6	1.8	1.5	0.0	0.0	0.2	1.0
Steelhead *O. mykiss*	0.0	0.0	0.0	–	0.0	–	–	–
Juvenile total	2.1	1.8	12.5	12.5	49.8	35.0	83.3	23.8
(% of total salmon)	(81)	(86)	(99)	(98)	(87)	(94)	(99)	(98)
Immature and adult salmon								
Pink salmon	0.0	0.0	0.0	0.1	2.8	0.8	0.3	0.1
Chum salmon	0.0	0.0	–	0.0	2.9	0.7	0.1	0.0
Sockeye salmon	0.0	0.0	0.0	0.0	0.9	0.3	0.0	–
Coho salmon	0.2	0.1	0.0	0.0	0.6	0.3	0.1	0.2
Chinook salmon	0.2	0.1	0.0	0.0	0.5	0.2	0.3	0.2
Steelhead	0.0	0.0	–	–	0.0	–	–	–
Immature-adult total	0.5	0.3	0.1	0.2	7.7	2.3	0.7	0.5
All other species								
All other species	97.4	97.9	87.4	87.3	42.5	62.7	16.0	75.7
Total	100	100	100	100	100	100	100	100

14). In the SS time period, Chinook salmon and coho salmon were associated with market squid in cluster E (Figure 13). Salmonids were indicator species of southwestern Vancouver Island and Washington, whereas market squid was an indicator species of Oregon. Pink salmon, chum salmon, and sockeye salmon were associated with walleye pollock and prowfish in cluster F. Most species in this cluster were indicative of the western Gulf of Alaska. Although this group also includes spiny dogfish *Squalus acanthias*, abundances of other species in the cluster were higher in the AC than in the CC. Pacific sand lance *Ammodytes hexapterus* was in its own cluster A and was a nonsignificant indicator species of the eastern Gulf of Alaska. Sablefish *Anoplopoma fimbria* and juvenile steelhead were grouped into cluster B. Sablefish was a nonsignificant indicator species of the western Gulf of Alaska. Juvenile steelhead was a weak, but significant indicator species of Washington. Wolf-eel *Anarrhichthys ocellatus*, Pacific tomcod *Microgadus proximus*, Pacific sardine, and jack mackerel *Trachurus symmetricus* were

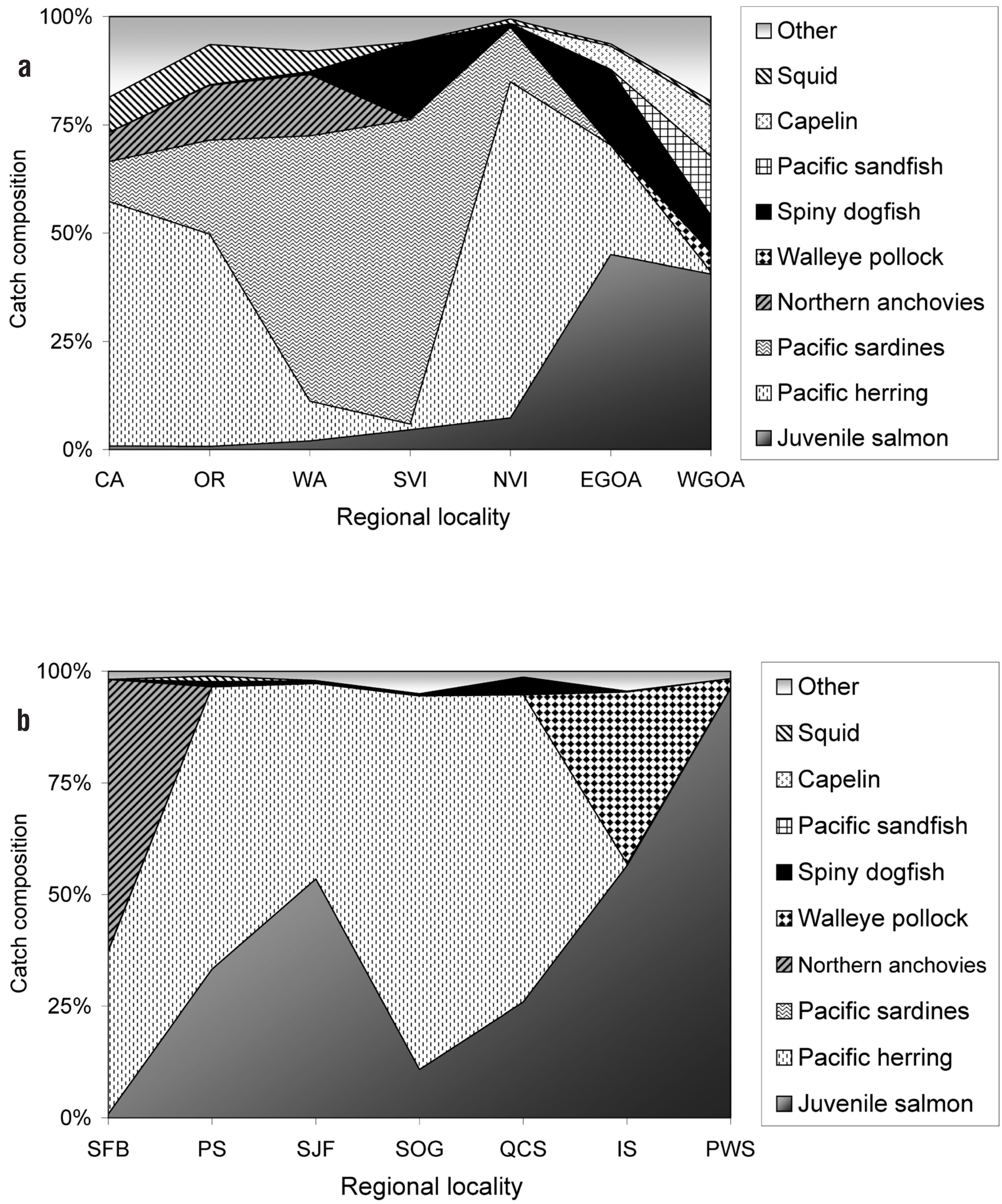


Figure 4. Catch composition by regional locality of juvenile salmon and dominant fish species and squid in the coastal waters (a) of the California Current (California, Oregon, Washington, southwestern Vancouver Island, northwestern Vancouver Island) and the Alaska Current (eastern Gulf of Alaska, western Gulf of Alaska), and inshore waters (b) of the California Current (San Francisco Bay, Puget Sound, Strait of Juan de Fuca, Strait of Georgia, Queen Charlotte Strait) and the Alaska Current (Icy Strait, Montague Strait) from May to October 2000–2004.

Table 7. Frequency of occurrence (FO, %) of neritic species occurring in ≥10% of day catches in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. For salmon species, the FO is shown initially for all life history types combined (i.e., juvenile, immature, and adult), and is shown below by juvenile salmon alone.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Species	SS	SF	SS	SF	SS	SF	SS	SF
Northern spearnose poacher *Agonopsis vulsa*	0	0	18	1	0	0	0	0
Pacific sand lance	5	0	9	6	12	9	1	0
Wolf-eel	11	7	19	3	3	4	5	3
Sablefish	6	4	3	0	11	11	0	0
Jacksmelt *Atherinopsis californiensis*	6	7	21	0	0	0	0	0
Crested sculpin *Blepsias bilobus*	0	0	0	0	2	4	46	56
Pacific herring	22	25	70	38	14	15	8	9
Northern anchovy	11	13	21	1	0	0	0	0
Medusafish *Icichthys lockingtoni*	5	16	0	0	0	0	0	0
River lamprey *Lampetra ayresii*	0	0	32	11	0	0	0	0
Market squid	27	25	2	0	0	0	0	0
Capelin *Mallotus villosus*	0	0	0	0	5	10	2	3
Pink salmon	5	9	42	58	82	82	74	85
Chum salmon	19	10	54	88	80	79	77	66
Coho salmon	48	38	60	88	67	61	73	60
Steelhead	9	3	1	0	1	0	0	0
Sockeye salmon	11	5	45	42	72	68	68	50
Chinook salmon	57	49	85	78	34	16	45	43
Pacific pompano *Peprilus simillimus*	3	6	15	0	0	0	0	0
Soft sculpin *Psychrolutes sigalutes*	0	0	1	0	2	4	3	23
Pacific sardine	20	19	8	0	0	0	0	0
Spiny dogfish	9	4	34	10	50	19	0	0
Walleye pollock *Theragra chalcogramma*	2	1	4	3	26	23	50	26
Jack mackerel	9	14	0	0	0	0	0	0
Pacific sandfish *Trichodon trichodon*	2	1	4	2	2	13	3	1
Prowfish *Zaprora silenus*	1	1	0	0	30	23	15	17
Juvenile salmon only								
Pink salmon	3	6	40	50	64	69	66	83
Chum salmon	17	9	54	86	58	66	76	66
Coho salmon	41	32	58	86	53	56	71	56
Steelhead	7	3	1	0	1	0	0	0
Sockeye salmon	8	4	43	41	62	63	68	50
Chinook salmon	44	38	84	77	4	1	23	33

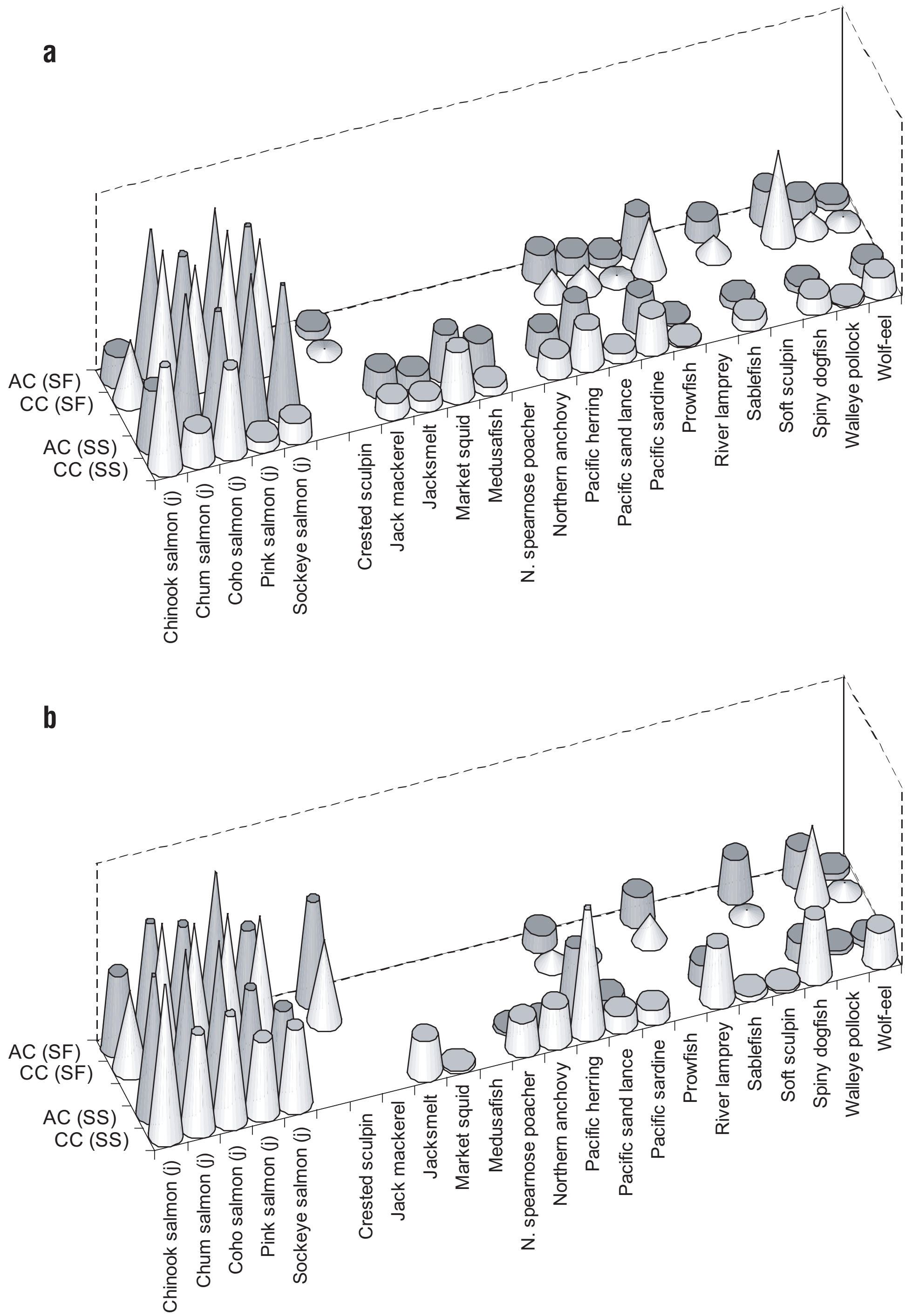


Figure 5. Frequency of occurrence of juvenile (j) salmon and associated species occurring in ≥10% of day catches in coastal (a) and inshore (b) localities of the California Current (CC) and the Alaska Current (AC) along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004.

Table 8. Average densities (numbers/km²) of dominant neritic fish and squid species in day catches in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. Species shown other than salmon had densities ≥ 250/km² in at least one time period/locality/current stratum.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Species	SS	SF	SS	SF	SS	SF	SS	SF
Pacific herring	4,038	1,321	11,731	5,423	9	319	17	9
Northern anchovy	1,333	371	1,796	0	0	0	0	0
Threespine stickleback *Gasterosteus aculeatus*	0	0	12	614	0	382	0	0
Market squid	414	527	0	0	0	0	0	0
Capelin	0	0	0	0	124	354	0	8
Pink salmon	13	33	435	198	424	584	1,595	334
Chum salmon	31	10	802	385	169	205	1,463	109
Coho salmon	67	45	389	140	67	113	168	49
Sockeye salmon	19	5	56	59	88	296	175	48
Chinook salmon	72	48	293	107	7	7	22	26
Steelhead	2	1	0	0	0	0	0	0
Pacific sardine	1,275	4,012	5	0	0	0	0	0
Spiny dogfish	189	34	89	34	287	43	0	0
Walleye pollock	4	0	1	1	48	118	592	1,558
Pacific sandfish	1	0	1	0	3	616	1	0
Juvenile salmon only								
Pink salmon	12	31	434	192	388	559	1,570	332
Chum salmon	31	10	802	383	130	182	1,460	109
Coho salmon	50	38	382	137	59	105	165	45
Sockeye salmon	17	5	55	58	77	286	174	48
Chinook salmon	53	39	291	105	0	0	8	2
Steelhead	2	0	0	0	0	0	0	0

grouped into cluster C and were indicative of California and southwestern Vancouver Island. Pacific herring, surf smelt *Hypomesus pretiosus*, and northern anchovy comprised cluster D. Pacific herring and northern anchovy were significant indicator species of California, whereas surf smelt was a nonsignificant indicator species of Washington.

In the SF time period for coastal habitat, juvenile Chinook salmon were associated with Pacific herring and market squid in cluster A (Figure 14). Although they had weaker associations, additional species in this cluster were wolf-eel, jacksmelt, medusafish, and Pacific tomcod. Species in this cluster were indicative of several localities, and jacksmelt and medusafish were moderate indicator species of California. Immature-adult pink salmon, chum salmon, and sockeye salmon were associated with walleye pollock and prowfish in cluster D. Immature-adult chum salmon were indicative of the eastern Gulf of Alaska, whereas other species in this cluster were indicative of the western Gulf of Alaska. Juvenile pink salmon, chum salmon, and sockeye salmon were

Table 9. Average densities (numbers/m$^3 \times 10^6$) of dominant neritic fish and squid species in day catches in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. Species shown other than salmon had overall densities $\geq 1 \times$ m$^3 \times 10^{-6}$.

	California Current				Alaska Current			
	Coastal		Inshore		Coastal		Inshore	
Species	SS	SF	SS	SF	SS	SF	SS	SF
Whitebait smelt *Allosmerus elongatus*	7.0	0.7	0.4	0.2	0.0	0.0	0.0	0.0
Pacific sand lance	0.6	0.0	0.4	1.8	1.0	6.2	0.0	0.0
Jacksmelt	6.0	11.9	63.5	0.0	0.0	0.0	0.0	0.0
Pacific herring	264.8	91.9	4,969.2	452.2	0.9	10.1	0.9	0.5
Pacific saury *Cololabis saira*	0.1	2.9	0.0	0.0	0.0	0.1	0.0	0.0
Northern anchovy	75.9	23.3	7,871.9	0.0	0.0	0.0	0.0	0.0
Threespine stickleback	0.0	0.0	0.7	52.4	0.0	28.6	0.0	0.0
Kelp greenling *Hexagrammos decagrammus*	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0
Surf smelt	6.6	3.8	0.5	0.0	0.0	0.0	0.0	0.0
Market squid	33.6	38.6	2.1	0.0	0.0	0.0	0.0	0.0
Capelin	0.0	0.0	0.0	0.0	6.8	14.8	0.0	0.6
Pink salmon	0.7	2.1	26.4	15.9	31.4	30.5	89.5	18.8
Chum salmon	1.8	0.6	53.1	32.3	14.5	10.5	82.0	6.4
Coho salmon	3.9	2.3	23.9	11.6	4.4	5.1	9.2	2.9
Sockeye salmon	1.0	0.3	3.4	4.5	5.8	16.4	9.8	2.6
Chinook salmon	4.3	2.7	118.6	9.6	0.5	0.3	1.2	1.6
Steelhead	0.2	0.0	0.2	0.0	0.6	0.4	0.0	0.0
Pacific pompano	0.5	0.7	96.7	0.0	0.0	0.0	0.0	0.0
Soft sculpin	0.0	0.0	0.0	0.0	0.0	0.1	0.0	8.3
Pacific sardine	72.5	238.5	16.8	0.0	0.0	0.0	0.0	0.0
Spiny dogfish	8.3	4.2	5.1	2.8	17.1	3.2	0.0	0.0
Walleye pollock	0.2	0.0	0.1	0.1	3.2	5.4	32.5	99.8
Jack mackerel	1.2	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Pacific sandfish	0.0	0.0	0.1	0.0	0.1	26.8	0.1	0.0
	Juvenile salmon only							
Pink salmon	0.7	2.0	26.3	15.4	29.0	29.4	88.8	18.7
Chum salmon	1.8	0.5	53.1	32.1	12.3	9.6	81.9	6.4
Coho salmon	3.0	2.0	23.5	11.4	3.9	4.7	9.1	2.6
Sockeye salmon	0.9	0.2	3.4	4.4	5.2	16.1	9.8	2.6
Chinook salmon	3.1	2.2	118.5	9.4	0.1	0.0	0.5	1.3
Steelhead	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0

associated with spiny dogfish in cluster E. The salmonids were moderate indicator species of the western Gulf of Alaska, whereas spiny dogfish was a weak, but significant indicator species of the eastern Gulf of Alaska. Coho salmon were associated with immature-adult Chinook salmon in cluster F, which is indicative of southwestern Van-

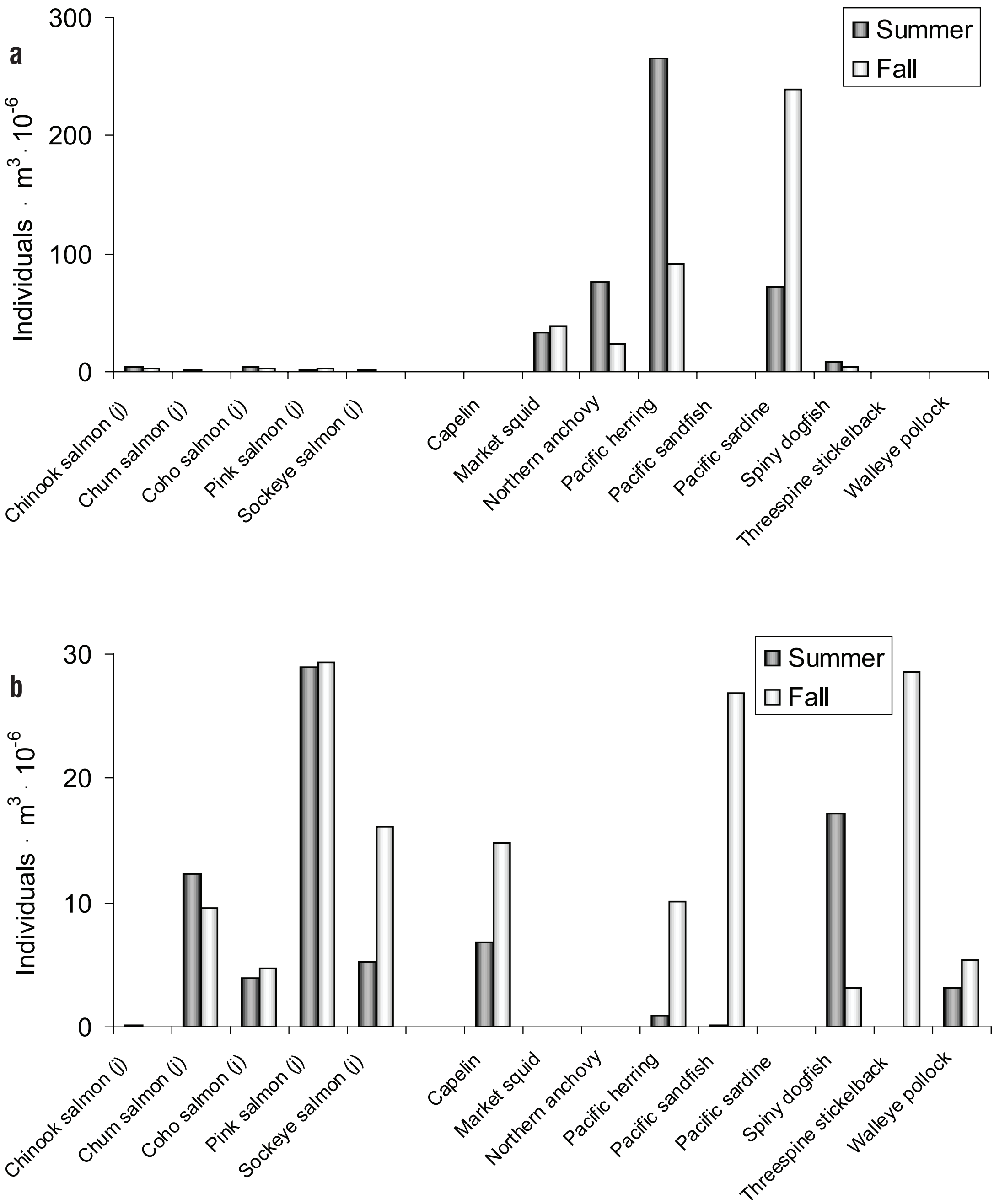
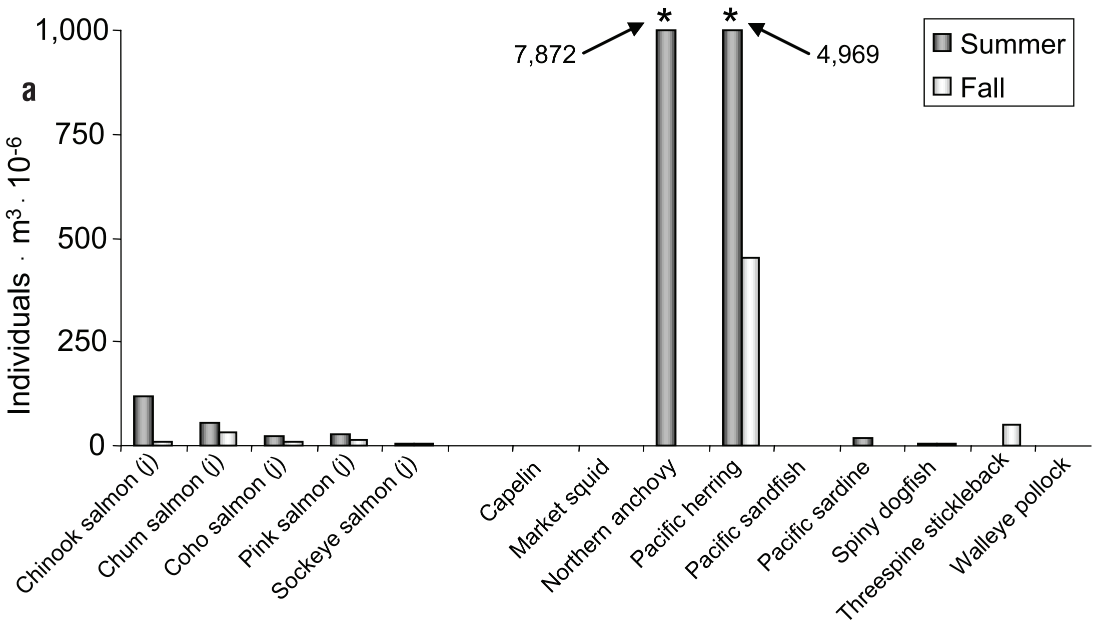


Figure 6. Relative average densities of juvenile salmon species to dominant fish and squid species in the coastal waters of the California Current (a) and the Alaska Current (b) captured using surface trawls in neritic waters along the west coast of North America during daylight hours, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. Note differences in scales between a and b.



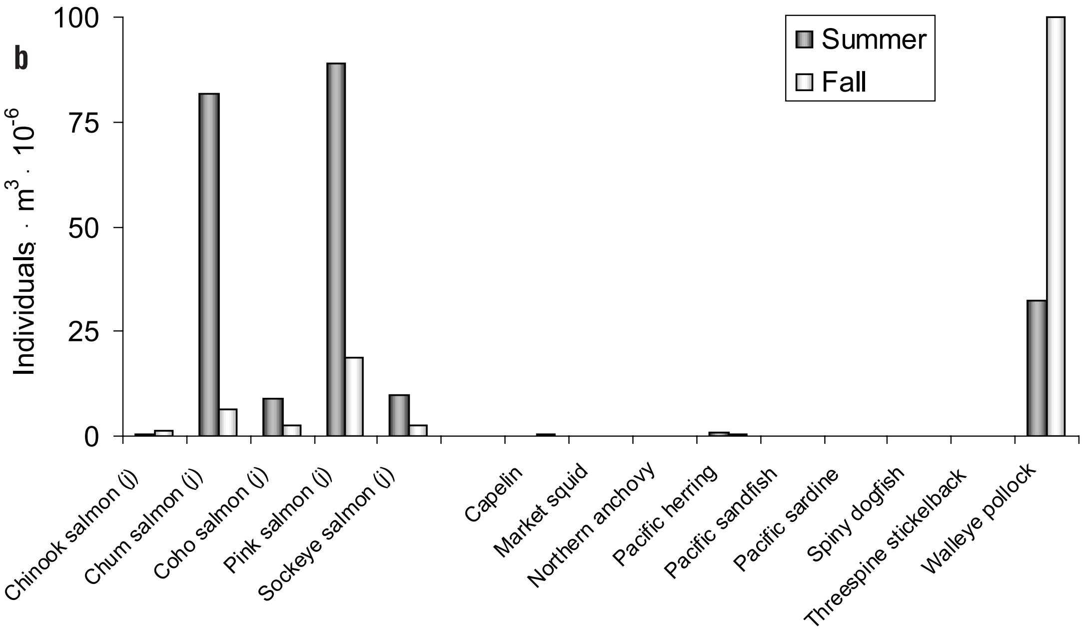


Figure 7. Relative average densities of juvenile salmon species to dominant fish and squid species in the inshore waters of the California Current (a) and the Alaska Current (b) captured using surface trawls in neritic waters along the west coast of North America during daylight hours, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004. Note differences between a and b.

Table 10. Diel catches of neritic fishes and squid by family group from repetitive rope trawl sampling at two coastal localities in the California Current, June and August 2002. Total km^2 is the surface area swept by the trawls. Total volume sampled (m^3) = total $km^2 \times 18$ m $\times 10^6$.

Family	Day rope trawls (0851–1858 hours)				Night rope trawls (2235–0301 hours)			
	Total hauls	Total km^2	Total catch	Catch per km^2	Total hauls	Total km^2	Total catch	Catch per km^2
Newport Hydroline (44.650ºN, 124.182ºW), June 7–8, 2002								
Anarhichadidae	3	0.267	1	4	2	0.175	0	0
Bothidae	3	0.267	0	0	2	0.175	2	11
Clupeidae	3	0.267	2	7	2	0.175	188	1,074
Engraulidae	3	0.267	0	0	2	0.175	19	109
Gadidae	3	0.267	0	0	2	0.175	3	17
Osmeridae	3	0.267	0	0	2	0.175	585	3,343
Salmonidae	3	0.267	20	75	2	0.175	9	51
Squid	3	0.267	124	464	2	0.175	121	691
Stromateidae	3	0.267	0	0	2	0.175	1	6
Total			147	551			928	5,303
Heceta Head (44.000ºN, 124.399ºW), August, 7–8 2002								
Anoplopomatidae	3	0.276	0	0	2	0.181	1	6
Bothidae	3	0.276	0	0	2	0.181	32	177
Carangidae	3	0.276	1	4	2	0.181	5	28
Carcharhinidae	3	0.276	2	7	2	0.181	0	0
Clupeidae	3	0.276	963	3,489	2	0.181	2,588	14,298
Engraulidae	3	0.276	4	14	2	0.181	13	72
Merlucciidae	3	0.276	0	0	2	0.181	270	1,492
Osmeridae	3	0.276	0	0	2	0.181	12	66
Petromyzontidae	3	0.276	0	0	2	0.181	1	6
Salmonidae	3	0.276	10	36	2	0.181	11	61
Squalidae	3	0.276	0	0	2	0.181	2	11
Squid	3	0.276	55	199	2	0.181	143	790
Total			1,035	3,750			3,078	17,006

couver Island. Sablefish and Pacific saury were grouped into cluster B and were non-significant indicator species of the eastern Gulf of Alaska and California, respectively. Northern anchovy, Pacific sardine, and jack mackerel were grouped into cluster C. In this cluster, Pacific sardine were indicative of Washington, jack mackerel were indicative of Oregon, and northern anchovy were indicative of California.

In the inshore habitat, the 30% cutoff resulted in four cluster groups (A to D) in the SS and SF time periods (Figures 15 and 16). In the SS time period, juvenile pink salmon, chum salmon, sockeye salmon, and coho salmon were associated with each other in cluster B (Figure 15). In this cluster, juvenile pink salmon were indicative of Montague Strait, juvenile chum salmon and sockeye salmon were indicative of Queen Charlotte Strait, and juvenile coho salmon were indicative of Strait of Georgia. Imma-

Table 11. Diel catches of neritic fishes and squid by family group from repetitive rope trawl sampling at one inshore locality in the Alaska Current, summer (June–July) and summer–fall (August–September) 2001. Total km^2 is the surface area swept by the trawls. Total volume sampled (m^3) = total km^2 $\times$ 18 m $\times$ 10^6.

	Day rope trawls (0700–1935 hours)				Night rope trawls (2143–0430 hours)			
Family	Total hauls	Total km^2	Total catch	Catch per km^2	Total hauls	Total km^2	Total catch	Catch per km^2
Icy Strait (58.260ºN, 135.440ºW), June 29–30 and July 30–31, 2001								
Clupeidae	13	0.540	2	4	4	0.175	1	6
Cyclopteridae	13	0.540	1	2	4	0.175	0	0
Gadidae	13	0.540	12	22	4	0.175	3,291	18,860
Hemitripteridae	13	0.540	11	20	4	0.175	1	6
Osmeridae	13	0.540	1	2	4	0.175	918	5,261
Salmonidae	13	0.540	1,123	2,082	4	0.175	115	659
Squid	13	0.540	0	0	4	0.175	7	40
Zaproridae	13	0.540	1	2	4	0.175	0	0
Total			1,151	2,133			4,333	24,831
Icy Strait (58.260ºN, 135.440ºW), August 28–30 and September 29–30, 2001								
Agonidae	12	0.498	1	2	4	0.166	0	0
Anarhichadidae	12	0.498	1	2	4	0.166	0	0
Clupeidae	12	0.498	0	0	4	0.166	12	72
Cyclopteridae	12	0.498	1	2	4	0.166	1	6
Gadidae	12	0.498	11,610	23,313	4	0.166	25,241	152,054
Hemitripteridae	12	0.498	12	24	4	0.166	2	12
Hexagrammidae	12	0.498	1	2	4	0.166	0	0
Osmeridae	12	0.498	22	44	4	0.166	3,707	22,331
Psychrolutidae	12	0.498	406	815	4	0.166	0	0
Salmonidae	12	0.498	287	576	4	0.166	185	1,114
Squid	12	0.498	1	2	4	0.166	7	42
Zaproridae	12	0.498	3	6	4	0.166	0	0
Total			12,345	24,789			29,155	175,633

ture-adult pink salmon, Chinook salmon, and coho salmon were grouped with crested sculpin, walleye pollock, and prowfish in cluster C. Immature-adult Chinook salmon and coho salmon were indicative of the Strait of Juan de Fuca, although this was not significant for Chinook salmon. Immature-adult pink salmon were a nonsignificant indicator species of Icy Strait. Crested sculpin and walleye pollock were moderate indicator species of Montague Strait. Juvenile Chinook salmon were mostly associated with Pacific herring but also were associated with jacksmelt, northern anchovy, Pacific pompano (also known as Pacific butterfish), and Pacific sardine in cluster D and were moderate to strong indicators of San Francisco Bay. Northern spearnose poacher, wolf-eel, river lamprey, spiny dogfish, and Pacific sand lance were grouped into cluster A. Northern spearnose poacher, wolf-eel, and river lamprey were moderate to strong

Table 12. Diel catches of neritic fishes and squid by family group from repetitive rope trawl sampling at a coastal locality in the western Gulf of Alaska in the Alaska Current, July 2001–2002. Total km^2 is the surface area swept by the trawls. Total volume sampled (m^3) = total $km^2 \times 10^6 \times 9$ m (for 2001) or 15 m (for 2002).

	Day rope trawls (0641–1933 hours)				Night rope trawls (2230–0335 hours)			
Family	Total hauls	Total km^2	Total catch	Catch per km^2	Total hauls	Total km^2	Total catch	Catch per km^2
Western Gulf of Alaska (59.536°N, 149.170°W), July 26–27, 2001								
Anoplopomatidae	4	0.779	75	96	2	0.381	11	29
Clupeidae	4	0.779	0	0	2	0.381	3,700	9,711
Gadidae	4	0.779	0	0	2	0.381	500	1312
Salmonidae	4	0.779	315	404	2	0.381	48	126
Squalidae	4	0.779	77	99	2	0.381	44	115
Zaproridae	4	0.779	0	0	2	0.381	1	3
Total			467	599			4,304	11,297
Western Gulf of Alaska (59.699°N, 149.330°W), July 26, 2002								
Ammodytidae	4	0.771	0	0	2	0.386	1	3
Clupeidae	4	0.771	12	16	2	0.386	2,205	5,712
Gadidae	4	0.771	1	1	2	0.386	67	174
Salmonidae	4	0.771	471	611	2	0.386	130	337
Scorpaenidae	4	0.771	1	1	2	0.386	0	0
Squalidae	4	0.771	2,206	28,61	2	0.386	1,554	4,026
Squid	4	0.771	0	0	2	0.386	5	13
Total			2,691	3,490			3,962	10,264

indicator species of Strait of Georgia. Spiny dogfish was an indicator species of Queen Charlotte Strait. Pacific sand lance was a nonsignificant and weak indicator species of Strait of Georgia. No species were indicative of Puget Sound.

In the SF time period for the inshore habitat, juvenile pink salmon, sockeye salmon, chum salmon, coho salmon, and Chinook salmon were associated with each other in cluster D (Figure 16). Juvenile pink salmon and sockeye salmon were indicator species of Montague Strait. Juvenile chum salmon and Chinook salmon were indicator species of Puget Sound. Juvenile coho salmon were an indicator species of Strait of Juan de Fuca. Immature-adult Chinook salmon and coho salmon were associated with Pacific herring and to a lesser degree, with river lamprey and spiny dogfish in cluster B. Immature-adult Chinook salmon and coho salmon and Pacific herring were significant indicator species of Puget Sound. River lamprey and spiny dogfish were weak and nonsignificant indicator species of Strait of Georgia and Queen Charlotte Strait, respectively. Immature-adult pink salmon and chum salmon were grouped into cluster C and were weak and nonsignificant indicator species of Strait of Georgia. Crested sculpin, walleye pollock, prowfish, and soft sculpin were grouped into cluster A, indicating an Alaska Current regional group. Crested sculpin, walleye pollock, and prowfish were moderate to strong indicator species of Montague Strait. Soft sculpin were indicative of Icy Strait.

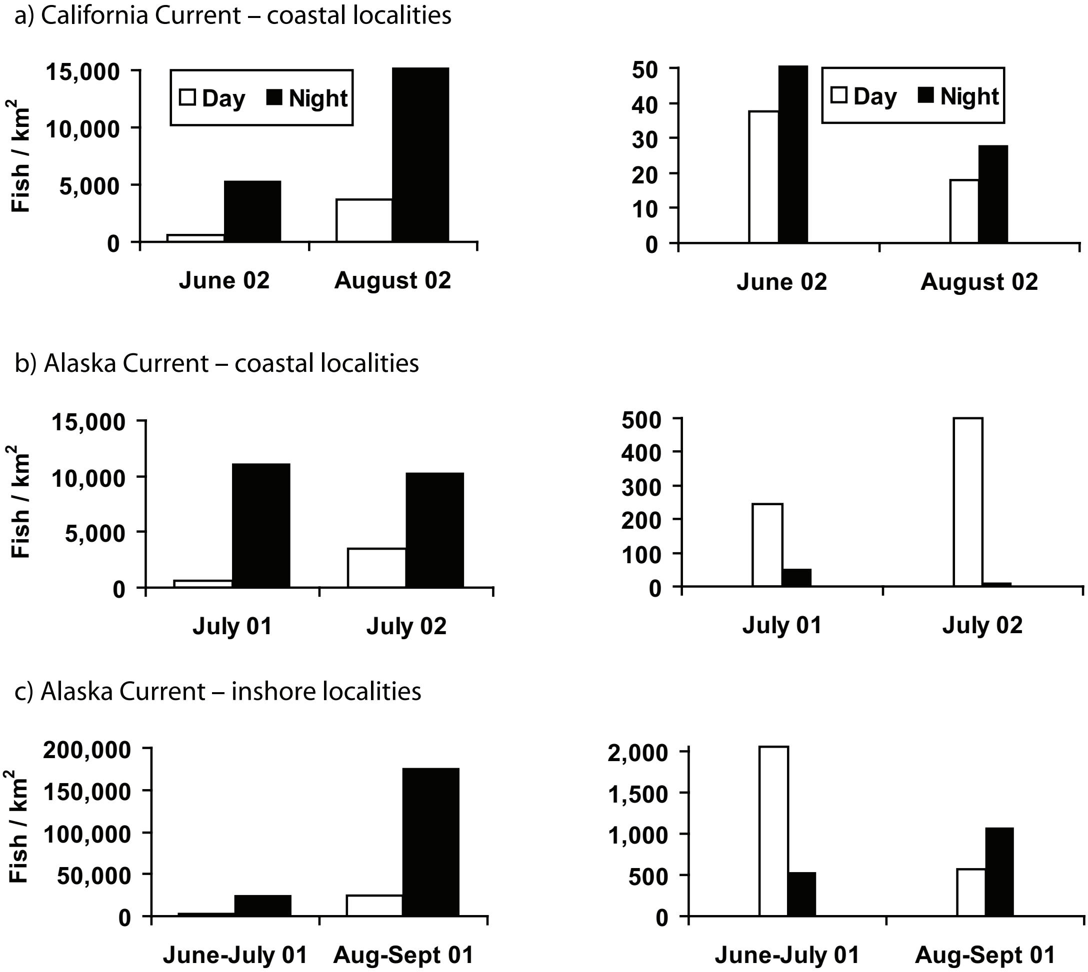


Figure 8. Examples of diel differences in total catch (left panels, wide bars) and juvenile salmon catch (right panels, narrow bars) in the California Current (a) and in the Alaska Current (b and c) in neritic waters along the west coast of North America. California Current examples are from two coastal localities in 2002, one in June and another in August. Alaska Current examples are from one coastal locality in July of 2001 and 2002, and one inshore locality in June–July and August–September 2001.

Nonmetric multidimensional scaling ordination of the SS nekton community is shown for two of the three axes in the three-dimensional solution. In the coastal habitat, the stress was high (22.0%), but instability was good (0.00001). The ordination explained 59.2% of the total variation in the data with axes 2 and 3 explaining 41.7% of the variation. Latitude and depth were correlated with axis 2 (r = 0.531 and 0.803, respectively), and temperature was correlated with axis 3 (r = 0.269). Although the community patterns are not obvious, there is a north to south distribution in the ordination plot (Figure 17A). The species centroids were overlaid primarily along axis 2 (Figure 17B). The three strongest correlations of species to axis 2 were juvenile pink salmon

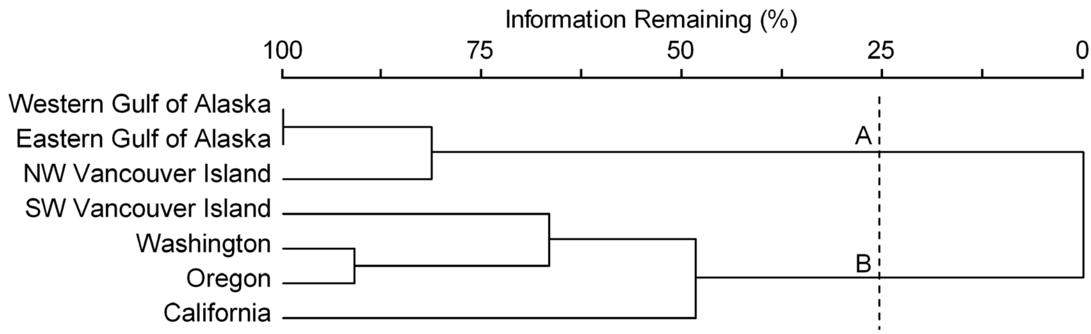


Figure 9. Cluster groupings of coastal localities on average species abundances in spring–summer. Dashed line indicates the 25% cutoff level for defining cluster groups. Localities groupings are identified by A and B.

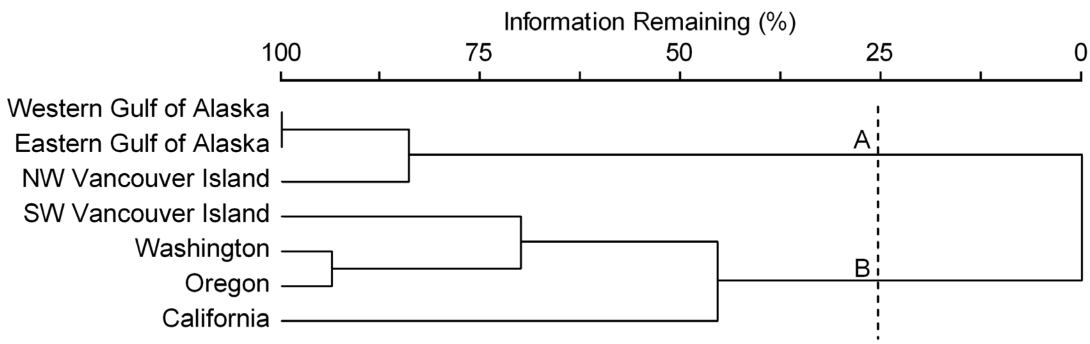


Figure 10. Cluster groupings of coastal localities on average species abundances in summer–fall. Dashed line indicates the 25% cutoff level for defining cluster groups. Localities groupings are identified by A and B.

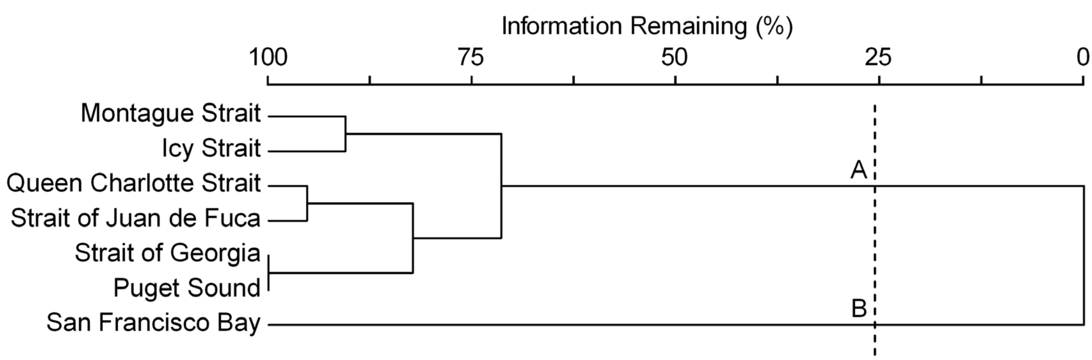


Figure 11. Cluster groupings of inshore localities on average species abundances in spring-summer. Dashed line indicates the 25% cutoff level for defining cluster groups. Localities groupings are identified by A and B.

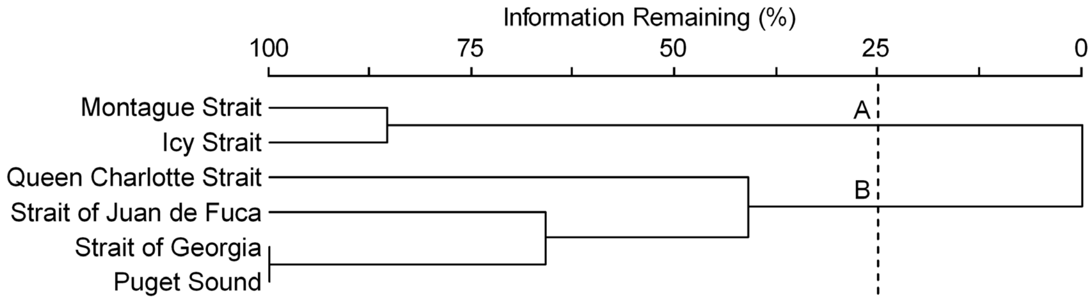


Figure 12. Cluster groupings of inshore localities on average species abundances in summer–fall. Dashed line indicates the 25% cutoff level for defining cluster groups. Localities groupings are identified by A and B.

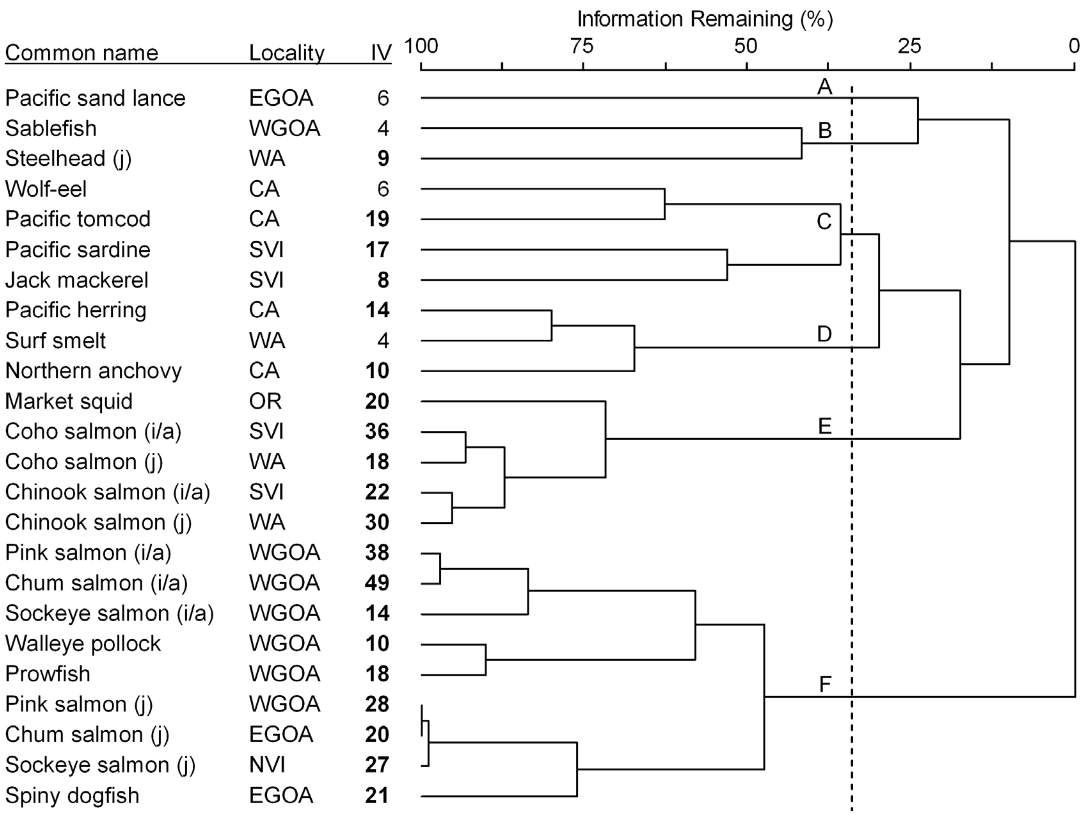


Figure 13. Cluster groupings of species associations in spring–summer and coastal habitat. Dashed line indicates the 35% cutoff level for defining cluster groups. Species groupings are identified by A–F. (j) indicates juvenile and (i/a) indicates immature-adult. The locality that species are indicative of and species maximum IV are listed. Maximum IV in bold represents significance at $P < 0.05$. CA = California, OR = Oregon, WA = Washington, SVI = southwestern Vancouver Island, NVI = northwestern Vancouver Island, EGOA = eastern Gulf of Alaska, and WGOA = western Gulf of Alaska.

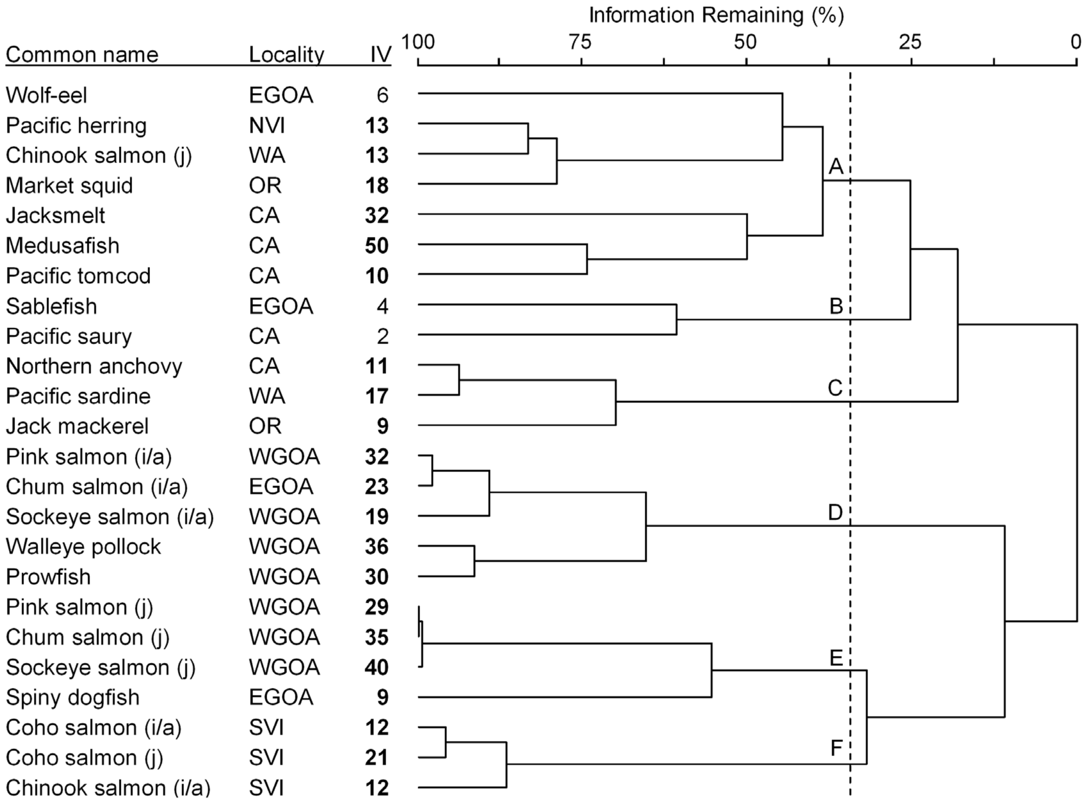


Figure 14. Cluster groupings of species associations in summer–fall and coastal habitat. Dashed line indicates the 35% cutoff level for defining cluster groups. Species groupings are identified by A–F. (j) indicates juvenile and (i/a) indicates immature-adult. The locality that species are indicative of and species maximum IV are listed. Maximum IV in bold represents significance at $P < 0.05$. CA = California, OR = Oregon, WA = Washington, SVI = southwestern Vancouver Island, NVI = northwestern Vancouver Island, EGOA = eastern Gulf of Alaska, and WGOA = western Gulf of Alaska.

(0.57), juvenile Chinook salmon (–0.52), and juvenile sockeye salmon (0.50), and to axis 3 were juvenile coho salmon (0.38), market squid (–0.31), and juvenile chum salmon (0.29). In the inshore habitat, the stress was fair (12.4%) and instability was good (0.00001). The ordination explained 91.0% of the variation in the data with axes 1 and 2 explaining 76.6% of the variation. Latitude and depth were correlated with axis 1 (r = 0.895 and 0.603, respectively), and temperature was negatively correlated with axis 2 (r = –0.503). There is a north to south distribution in the ordination plot (Figure 18A). Hauls clustered more tightly in the San Francisco Bay locality than in other localities. Much of the variation in the species centroids was associated with axis 1 (Figure 18B). The three strongest correlations of species to axis 1 were Pacific herring (–0.89), juvenile Chinook salmon (–0.72), and jacksmelt (–0.67), and to axis 2 were juvenile coho salmon (–0.52), walleye pollock (0.50), and river lamprey (–0.41). Ordination of SF in both coastal and inshore habitats was not possible. For coastal habitat, the

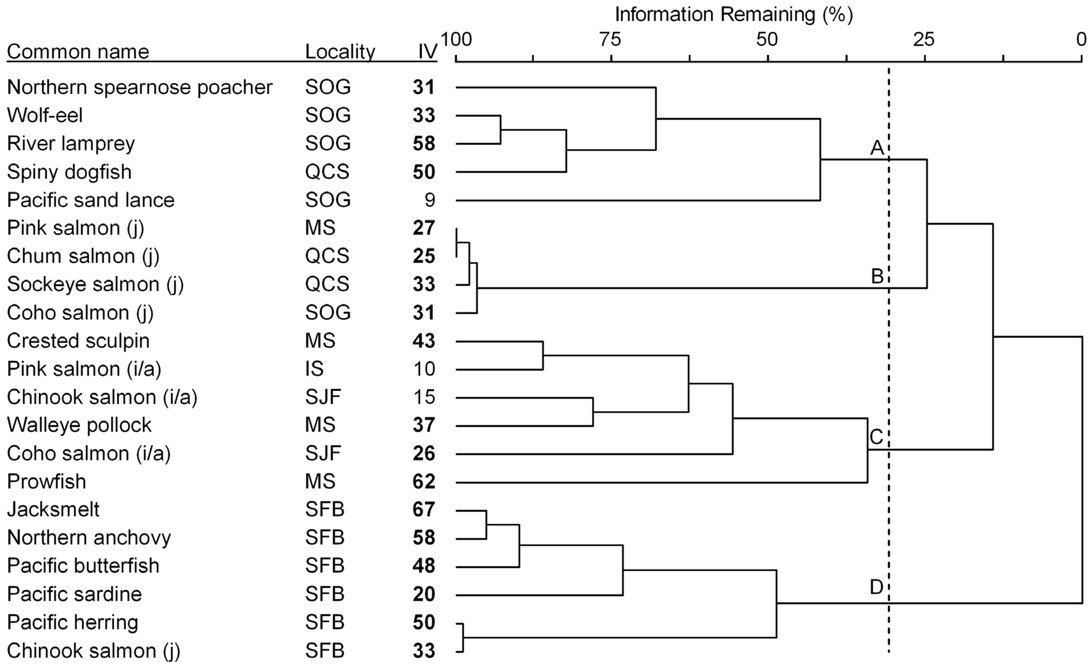


Figure 15. Cluster groupings of species associations in spring–summer and inshore habitat. Dashed line indicates the 30% cutoff level for defining cluster groups. Species groupings are identified by A–D. (j) indicates juvenile and (i/a) indicates immature-adult. The locality that species are indicative of and species maximum IV are listed. Maximum IV in bold represents significance at $P < 0.05$. SFB = San Francisco Bay, PS = Puget Sound, SJF = Strait of Juan de Fuca, SOG = Strait of Georgia, QCS = Queen Charlotte Strait, IS = Icy Strait, and MS = Montague Strait.

hauls-by-species matrix required reshuffling data too many times. This is likely because the matrix did not have a sufficient amount of abundance data. For inshore habitat, the ordination stress exceeded a satisfactory level and instability was low.

Discussion

Our study of epipelagic fish assemblages supports an ecosystem-based approach to management (EAM), the ocean resource management paradigm that has recently emerged as a primary mission goal of the U.S. National Oceanic and Atmospheric Administration (NOAA 2005). Attaining this goal will require inventories and comparisons of fish assemblages in marine ecosystems because it is inherently difficult to estimate fish abundance and to characterize and predict ecosystem structure and function. Furthermore, an EAM requires monitoring abundances of both noncommercial and commercial species. Indices of species composition can provide indicators enabling researchers to assess changes in community structure or help managers respond accordingly to such changes (Mueter and Norcross 2002). Fisheries managers are aware of their responsibility to a community of species, but regrettably are almost forced to consider one species at a time because they frequently lack a community framework needed to assess a plethora of species information (Apol-

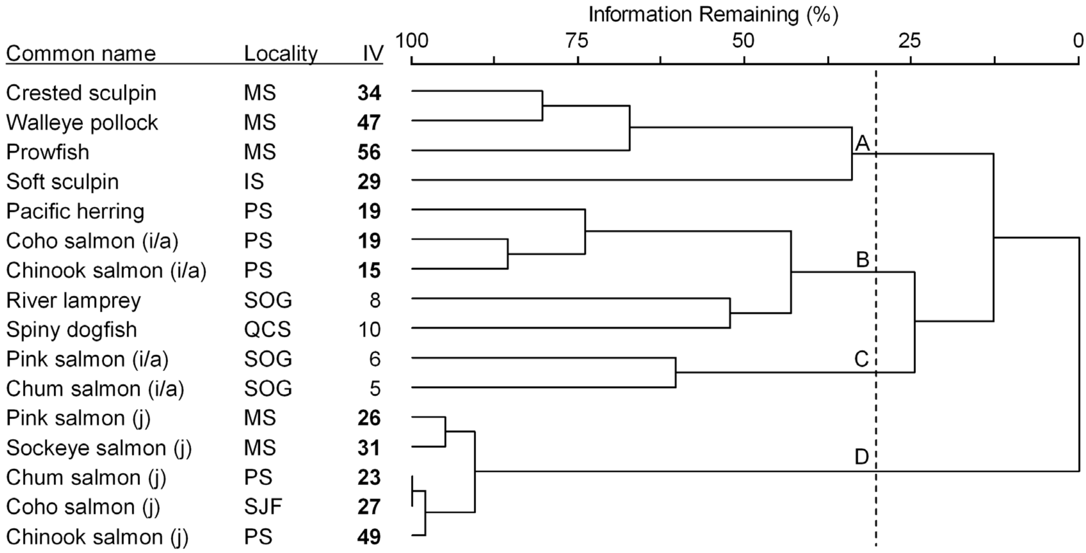


Figure 16. Cluster groupings of species associations in summer–fall and inshore habitat. Dashed line indicates the 30% cutoff level for defining cluster groups. Species groupings are identified by A–D. (j) indicates juvenile and (i/a) indicates immature-adult. The locality that species are indicative of and species maximum IV are listed. Maximum IV in bold represents significance at $P < 0.05$. PS = Puget Sound, SJF = Strait of Juan de Fuca, SOG = Strait of Georgia, QCS = Queen Charlotte Strait, IS = Icy Strait, and MS = Montague Strait.

lonio 1994). Characterizing fish assemblages in different habitats along the ocean migration routes of juvenile salmon helps provide a community framework for assessing interactions among species, thereby enabling us to better understand and model ecosystem dynamics in support of an EAM.

This study identified distinct differences in epipelagic fish assemblages associated with juvenile salmon between the neritic waters of the CC and those of the AC. Clupeids (i.e., Pacific herring and Pacific sardines) and juvenile salmonids were numerically dominant during day catches in the CC and AC regions, respectively. Other research within portions of the CC and AC regions support these findings. In the coastal waters of the northern CC region, Brodeur et al. (2004) reported that dominant species included Pacific herring, rockfishes, and Pacific sardines, whereas juvenile salmon represented only about 2% to 3% of the catch in June and August. In a 5-year study off Washington and Oregon, Brodeur et al. (2005) also found salmonids to represent a small fraction of the pelagic nekton caught. Although salmon occurred most frequently, pelagic schooling nekton such as Pacific herring, Pacific sardine, and northern anchovy comprised the bulk of the catches. Based on acoustic and midwater trawling operations in the coastal waters of the CC, Mais (1974) reported overwhelming evidence that northern anchovies were the dominant species in terms of biomass. In inshore waters of the CC, Beamish and McFarlane (1999) indicated that Pacific hake *Merluccius productus* and Pacific herring were dominant fishes in the Strait of Georgia, with the abundance of juvenile salmon substantially lower.

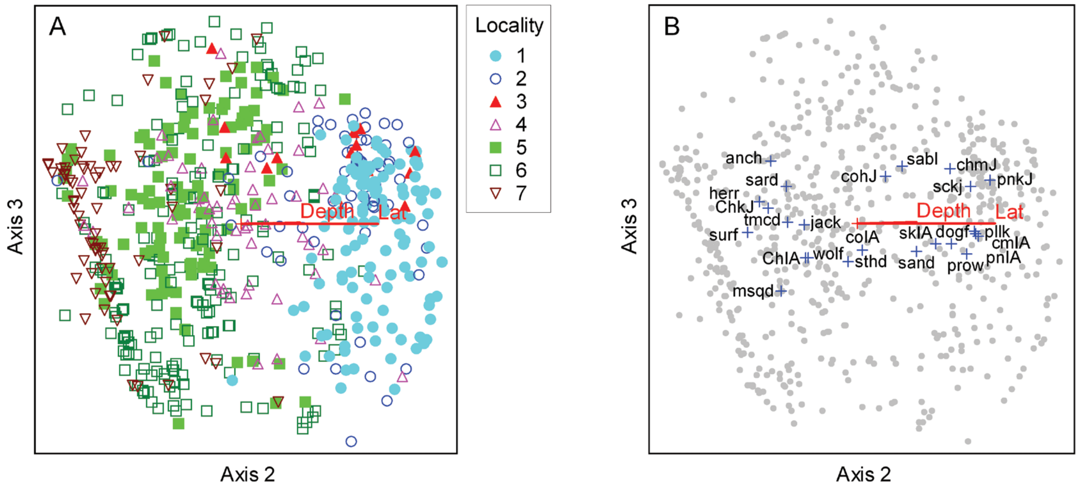


Figure 17. Nonmetric multidimensional scaling ordination plot of hauls as sampling units in species space for spring–summer time period and coastal habitat. Latitude (Lat) and depth (Depth) are shown as vectors and labeled. Temperature is not visible on the plot. In the left plot (A), the locality where each haul was collected from is represented by a symbol (1 = western Gulf of Alaska, 2 = eastern Gulf of Alaska, 3 = northwestern Vancouver Island, 4 = southwestern Vancouver Island, 5 = Washington, 6 = Oregon, 7 = California). In the right plot (B), hauls are plotted with an overlay of species weighted averages (anch = northern anchovy, ChIA = immature-adult Chinook salmon, ChkJ = juvenile Chinook salmon, cmIA = immature-adult chum salmon, chmJ = juvenile chum salmon, coIA = immature-adult coho salmon, cohJ = juvenile coho salmon, dogf = spiny dogfish, herr = Pacific herring, jack = jack mackerel, msqd = market squid, pllk = walleye pollock, pnIA = immature-adult pink salmon, pnkJ = juvenile pink salmon, prow = prowfish, sabl = sablefish, sand = Pacific sand lance, sard = Pacific sardine, sckJ = juvenile sockeye salmon, skIA = immature-adult sockeye salmon, sthd = juvenile steelhead, surf = surf smelt, tmcd = Pacific tomcod, wolf = wolf-eel).

In contrast, surface rope trawl surveys in the coastal and inshore regions of the AC from May to October have indicated that juvenile salmon are the predominant catch component in day sampling (Orsi et al. 2000).

The high abundance of clupeids and other fishes associated with juvenile salmon in the CC region compared to their abundance in the AC region have implications for competitive interactions in each region. Due to higher associated fish densities in the CC region, interactions among juvenile salmon species and associated species are probably substantially higher in the CC region than in the AC region. Salmon species have often been divided into two ecological groups: marine planktivores (pink salmon, chum salmon, and sockeye salmon) and marine piscivores (coho salmon and Chinook salmon) (Mundy and Hollowed 2005; Brodeur et al. 2007, this volume). In the current study, the relative abundance of these two groups indicated that planktivorous salmon species were highest in the AC region, while one of the piscivorous species (Chinook salmon) was highest in abundance in the CC region. Because Pacific herring, Pacific sardines, and northern anchovies forage at similar trophic levels as planktivorous juvenile salmon, and to a lesser extent piscivorous juvenile salmon, species interactions

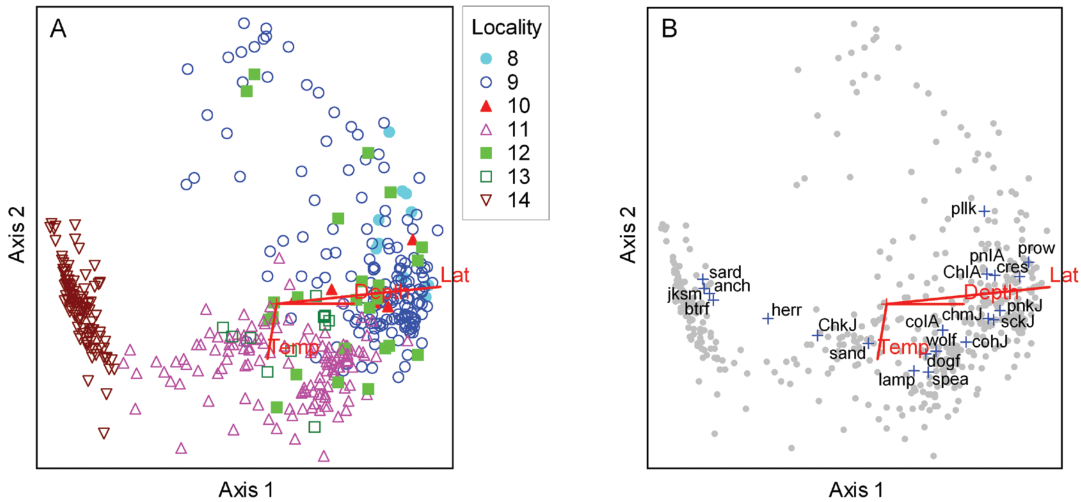


Figure 18. Nonmetric multidimensional scaling ordination plot of hauls as sampling units in species space for spring–summer time period and inshore habitat. Latitude (Lat), depth (Depth), and temperature (Temp) are shown as vectors and labeled. Temperature is not visible on the plot. In the left plot (A), the locality where each haul was collected from is represented by a symbol (8 = Montague Strait, 9 = Icy Strait, 10 = Queen Charlotte Strait, 11 = Strait of Georgia, 12 = Strait of Juan de Fuca, 13 = Puget Sound, 14 = San Francisco Bay). In the right plot (B), hauls are plotted with an overlay of species weighted averages (anch = northern anchovy, btrf = Pacific butterfish, ChlA = immature-adult Chinook salmon, ChkJ = juvenile Chinook salmon, chmJ = juvenile chum salmon, colA = immature-adult coho salmon, cohJ = juvenile coho salmon, cres = crested sculpin, dogf = spiny dogfish, herr = Pacific herring, jksm = jacksmelt, lamp = river lamprey, pllk = walleye pollock, pnlA = immature-adult pink salmon, pnkJ = juvenile pink salmon, prow = prowfish, sand = Pacific sand lance, sard = Pacific sardine, sckJ = juvenile sockeye salmon, spea = northern spearnose poacher, wolf = wolf-eel).

in the CC region may increase competition for prey resources, which could affect growth and survival among salmon species. Beamish et al. (2001) suggested that because juvenile Pacific herring and juvenile coho salmon eat similar prey, competition with Pacific herring could have affected survival under certain ocean conditions. Salmon are diurnal predators, which would minimize foraging interactions with other abundant species, such as Pacific herring, that are more abundant in epipelagic waters at night due to vertical diel migrations (Blaxter and Holliday 1963). During nocturnal epipelagic sampling in the Columbia River plume in the CC from May to July, Emmett et al. (2006) identified northern anchovy, Pacific herring, whitebait smelt, and Pacific sardine to be four important pelagic forage fishes. Nocturnal epipelagic sampling in the inshore waters of the AC from July to August has also identified high abundances of walleye pollock and eulachon *Thaleichthys pacificus* (Orsi et al. 2004). The interactions of juvenile salmon and associated species in epipelagic waters are probably higher in the CC than the AC and intensify in both regions at night.

In the context of studying epipelagic marine ecosystems of the CC and AC regions, it is important to recognize the dominant species in all areas of the water column, particularly for those species that utilize epipelagic waters at night. Stock assessment surveys using bottom trawls, conducted off the west coast of North America triennially by NMFS, identified important species that undergo vertical diel migrations from the demersal to the epipelagic habitat. This survey information, collected over the continental shelf and upper slope, overlies the sampling localities in the CC and AC regions of this study. Studies using this survey information have identified principal demersal fish species in each region. In the CC region off the coast of California, Oregon, and Washington, Jay (1996) reported that Pacific hake dominated assemblages on the continental shelf and slope and suggested that this species plays a large role in the dynamics of demersal fish communities. Pacific hake have also been described as an important trophic link in the CC ecosystem (Bailey et al. 1982). In the AC in the Gulf of Alaska, Mueter and Norcross (2002) found arrowtooth flounder *Atheresthes stomias*, walleye pollock, Pacific cod *Gadus macrocephalus*, and Pacific halibut *Hippoglossus stenolepis* to be species with the highest mean catch per unit effort (>1,500 kg/km^2) and FO (77–91%) over the continental shelf and upper slope. Walleye pollock have been characterized as an ecologically dominant and economically important species in the western Gulf of Alaska (Mundy and Hollowed 2005). Both walleye pollock and Pacific hake undergo vertical diel migrations to surface waters at night (Bailey et al. 1982; von Szalay 2003; Krutzikowsky and Emmett 2005). In the diel comparisons of this study, both walleye pollock and Pacific hake were more abundant at night. Therefore, diel interactions of these dominant species in each region are important considerations in understanding ecosystem dynamics with juvenile salmonids and other species in epipelagic marine habitats.

The regional assemblages for the coastal nekton determined by cluster analysis were remarkably similar between the two seasonal periods. Both analyses show a high similarity in nekton between the eastern and western Gulf of Alaska and, to a lesser extent, northwest Vancouver Island. Southwest Vancouver Island was consistently grouped with Washington, Oregon, and California, implying that there is a transition in pelagic fauna occurring somewhere along the west coast of Vancouver Island. In the most complete analysis to date of the zoogeographic patterns of fish species, including both pelagic and demersal fishes, Allen and Smith (1988) also found that the boundary between the Aleutian and Oregonian provinces occurs off northern Vancouver Island. In the inshore fauna, there were major differences between the two northern locales in Montague Strait and Icy Strait versus the remaining areas starting inside of Vancouver Island. Because of the large gap in sampling between these two major assemblages (i.e., 850 km), it was not possible to determine whether any sharp zoogeographic discontinuities exist. Also diminishing our ability to identify discontinuities, we pooled several years in our analysis and the ranges of mobile pelagic species assemblages are likely to change under different oceanographic conditions (Brodeur et al. 2003, 2005).

In terms of coastal species assemblages, we found some delineation of groupings based on latitude and, to a lesser extent, bottom depth. Chinook salmon and coho salmon generally clustered together with more southern species such as market squid, northern anchovy, and surf smelt, although Pacific herring, which had a broad distribution throughout the range we sampled, was associated with juvenile Chinook salmon late in the year. Sablefish, Pacific saury, Pacific sardines, and northern anchovy (late sampling only) were often associated with each other as an offshore (as defined by bottom depth) and southern assemblage. These assemblages are similar to those found in earlier studies of the California Current (Brodeur et al. 2004, 2005), although more intensive sampling in these studies relative to the same number of cluster groups enabled greater fine scale spatial resolution in the assemblages. In the northern region, pink salmon, chum salmon, and sockeye salmon juveniles were consistently grouped with spiny dogfish and the immature-adult salmonids were grouped with walleye pollock and prowfish. Pacific sand lance was found in both regions in the earlier (SS) seasonal period, which perhaps resulted in this species being classified as its own cluster and not a significant indicator of any particular region.

The inshore assemblages also showed some consistent patterns. Generally, all juvenile salmon clustered together in SS and SF seasonal periods with the exception of Chinook salmon in the earlier (SS) period, which were grouped with a number of small pelagic fishes and particularly with Pacific herring. Spiny dogfish, walleye pollock, and other potential predators were not associated with juvenile salmon in inshore regions, although they were often associated with immature-adult salmonids.

In our ordination analysis, latitude and bottom depth were correlated with stations. In the coastal habitat, this may be because the survey area in northern Gulf of Alaska is oriented from east to west, whereas from southeastern Alaska to California, the survey area is oriented from north to south. In addition, stations over the continental shelf in Gulf of Alaska were generally deeper than those to the south. A similar trend is observed in the inshore habitat. Montague Strait and Icy Strait are in Alaska, whereas other inshore localities are to the south. The correlation of temperature along axis 2 of the inshore localities may be due to smaller-scale differences in freshwater and marine input in the different regions. Additional environmental parameters were not available for all hauls to examine whether another environmental variable better explains the community structure of epipelagic nekton.

Several potential predators of juvenile salmon were identified in the assemblages of both the CC and the AC regions. One abundant predator species found in both regions was the spiny dogfish. This species had high frequencies of occurrence and density in each current system, particularly in coastal waters. Spiny dogfish are known to be predators of juvenile salmon (Larkin 1977; Beacham 1991; Beamish et al. 1992; Orsi et al. 2000) and are characterized as having a ubiquitous and abundant distribution in the North Pacific Ocean from California to Alaska (McFarlane and King 2003). Immature and adult salmon are other predatory species that occurred in low abundance in our samples from both regions. Active commercial salmon fisheries in both regions suggest that abundances are actually higher than our results indicate, probably due to gear selectivity or differences in fishing localities. Aggregations of maturing salmonids are generally harvested closer to shore or inland with seines, troll gear, or gill nets rather than the surface trawls that we fished in more offshore waters. Other studies have documented additional predator species, for example, Pacific chub mackerel *Scomber japonicus* off the coast of southern Vancouver Island (NRC 1996), river lamprey in the Strait of Georgia (Beamish and Neville 1995), Pacific hake, jack mackerel, Pacific mackerel, and spiny dogfish from May to July off the Columbia River plume (Emmett et al. 2006). In Barkley Sound, Beacham (1991) found Pacific hake to be the most important predator on juvenile salmon. Walleye pollock, particularly abundant in inshore waters in the AC, have also been identified as a juvenile salmon predator in Barkley Sound (Beacham 1991). In Prince William Sound, Willette et al. (2001) suggested that observed trends in salmon survival could be explained by walleye pollock predation when their alternate prey of copepods was low. In southeastern Alaska, Armstrong and Winslow (1968) found walleye pollock to feed on juvenile pink salmon, chum salmon, and coho salmon during darkness, and in coastal and inshore areas of the AC. Orsi et al. (2000) found that immature sablefish, adult coho salmon, Pacific sandfish, and spiny dogfish preyed on juvenile salmon.

Diel comparisons in this study indicated dramatic increases in total catch at night in both the CC and AC, but no consistent differences for juvenile salmon. This result is principally due to two factors, species vertically migrating to epipelagic waters at night (as previously discussed) and increased vulnerability of most species to capture at night in the trawl (Wardle 1986). Other studies using epipelagic trawls have indicated nocturnal increases in small pelagic species and predatory species co-occurring with juvenile salmon in the coastal waters of the CC (Emmett et al. 2004; Krutzikowsky and Emmett 2005) and the inshore waters of the AC (Orsi et al. 2004).

Because juvenile salmon are daylight predators, opportunities for foraging interactions with other abundant species that undergo vertical diel migrations would be minimized during daylight at the surface. In addition, relatively longer summer day lengths in northern latitudes of the AC compared to the CC would increase the effective foraging time for juvenile salmon and decrease potential interaction times with nocturnal predators or competitors. For example, at the approximate mid-latitude positions of data collections in the AC (60°N) and CC (45°N) regions, day length in mid-June is 3 h longer in the AC (18.4 h) than in the CC region (15.4 h). The extended day length in summer, coupled with relatively low abundances of co-occurring species in the AC region, gives juvenile salmon in the AC a relatively longer opportunity to forage with reduced competition and predation risk at night.

Each day and night comparison in this study was conducted with the same vessel and trawl gear and at the same locality within an approximate 24-h period. Using these criteria minimized potential bias in catch resulting from differential gear or vessel efficiency and any temporal effects due to sampling several days later at the same locality. The latter is particularly important because the water mass sampled at a ground-relative position may change drastically in time due to transport or surface currents. For example, within 35 km of the coast in the AC region, the speed of the Alaska Coastal Current can range from 17 to 138 km/d (20–160 cm/s; Mundy and Olsson 2005). In addition to large temporal variation in current velocities over the short term, fish concentrations can also be mobile through time. Using a new instantaneous continental shelf-scale imaging technique, Makris et al. (2006) revealed that within a 24-h period, fish shoals in continental shelf environments dramatically change their day-to-night migrations, both vertically and horizontally. Observations in this study validated dramatic nocturnal shifts in species assemblages within 24-h periods. Consequently, future studies on epipelagic fish assemblage dynamics should continue to partition out day and night sampling periods, and diel studies should restrict sampling to the same locality within as near a 24-h period as possible.

Fish density estimates made during day sampling were assumed to represent integrated species compositions and densities in epipelagic communities in neritic waters, despite some variability in trawl dimensionality. The average footrope depths of the different trawls varied from 11 to 18 m, and data from a shallower (3 m) trawl was used exclusively in one locality and time period in the CC (i.e., San Francisco Bay in SF). It is probable that the fish catches from the shallower trawls, particularly the 3-m trawl, yielded relatively higher densities of more surface-oriented species. Conversely, it is possible that some epipelagic species, like juvenile salmon, were not fully represented in trawls fishing even the deepest footrope depths. One study using depth-stratified trawls off the Columbia River plume found that the vertical distribution of juvenile salmon and other associated species was primarily within the upper 12 m of the water column (Emmett et al. 2004). However, based on surface trawls fished at differential depths in the Strait of Georgia, Beamish et al. (2000) found that 37% of juvenile coho salmon were distributed below 15 m. Additionally, in a study using troll gear in coastal and inshore marine waters of southeastern Alaska in September, Orsi and Wertheimer (1995) found 11% of juvenile coho salmon and 22% of juvenile Chinook salmon deeper than 30 m. Several assumptions in this study may have influenced the outcome of the results. The main sources of error stem from the different trawl types used and the respective fishing practices employed. Because trawl openings, speed, and surface orientation differed among studies, the assumption that the area or volume sampled by one trawl and vessel combination was directly comparable to another may be questionable. In a study comparing species assemblages using different trawls and vessels, Jay (1996) noted that even with constant trawl durations, the distance towed and area sampled may vary among hauls due to variable fishing conditions and vessel specifications. Similarly, Mueter and Norcross (2002) suggested that difference among trawl types may have biased some of their results. Trawl tow speed could influence capture rate of faster-swimming species during day sampling, for example, Emmett et al. (2006) noted that large predatory fishes such as adult salmon avoided the surface trawl during the day at speeds of 1.5 m/s. Thus, faster tow speeds would be more effective in capturing larger pelagic predators during day, and faster tow speeds at night may be the best combination to effectively capture larger pelagic predators. Another important factor potentially biasing trawl catches is fishing proximity to the surface. Trawls with headropes improperly buoyed, or fished in rough sea states, will not effectively sample the near-surface layer and therefore underrepresent catches of surface-oriented species.

The prevalence of some surface-oriented species is almost certainly related to environmental factors to a significant degree, for example, regional differences in surface (2–4 m) temperatures in the CC and the AC regions. Average SS and SF temperatures in coastal localities were cooler in the CC (12.0–12.2°C) than in the AC (12.8–13.3°C). Within the northeast Pacific Ocean, the CC region is within a Coastal Upwelling Domain and the AC region within the Coastal Downwelling Domain (Ware and McFarlane 1989; Ware and Thomson 2005) (i.e., CC localities were within cooler upwelled waters). However, at inshore localities relatively cooler average SS and SF temperatures occurred in the AC (11.6–12.2°C) compared to the CC (12.1–14.4°C) region. The cooler temperatures in the inshore waters of the AC may be due to several factors (e.g., discharge from tidewater and terrestrial glaciers, reduced solar radiation due to cloud cover, and relatively greater snow pack in the coastal mountain range). These factors, when coupled with rainfall in the region, which can amount to 2–6 m per year (Weingartner et al. 2005), result in an abundant supply of cold, freshwater that increases through summer and peaks in the fall (Royer 2005) and drives the Alaska Coastal Current, a low-salinity feature within the AC. This may explain why the average water temperatures were coldest in the inshore waters of the AC, particularly in SS, which generally was associated with the highest densities of juvenile pink salmon, chum salmon, and sockeye salmon.

This study describes the principal epipelagic fish assemblages associated with juvenile salmon in neritic waters of the CC and the AC for the 5-year period 2000–2004. The information summarized did not lend itself to interannual comparisons because not all years or seasons were sampled in each region. Other studies of neritic communities examined temporal patterns and found that annual differences in species composition and abundance do exist, possibly as a result of climate change (Beamish and Bouillon 1993; Emmett and Brodeur 2000; Brodeur et al. 2005). This study examined spatial patterns of abundance of epipelagic fish assemblages associated with juvenile salmon as they migrate seasonally through inshore and coastal habitats. Juvenile salmon are surface oriented and are known to spend their first summer of marine life in coastal waters (Myers et al. 2000) where they appear to orient to circulation features during their migratory ocean life history as opposed to species like Pacific herring that have more localized distributions and utilize diel vertical movement as a foraging strategy (Blaxter and Holliday 1963; Ware and Thomson 2005).

Future studies of epipelagic fish assemblages in marine ecosystems should incorporate species size data and a more complete description of their seasonal habitat utilization patterns. If consistent species size data had been available in this study, then estimates could have been made of species-specific biomass by region. Biomass estimates of species should also include the large gelatinous taxa that can be a substantial component of the biomass in the surface trawl catches (Suchman and Brodeur 2005). Quantifying large gelatinous taxa would also enable net efficiency to be evaluated as large catches of jellyfish are thought to reduce the effectiveness of the trawl. Future studies of epipelagic fish assemblages also need finer temporal resolution within years to detect possible shifts in seasonal abundance; these shifts are likely to be the first consequence of climate change or localized warming. In addition to finer resolution sampling in critical periods, there is also a need for extended seasonal sampling. Our sampling of assemblages only covered half the year (May–October), therefore, year-round residence patterns of epipelagic species in neritic waters could not be evaluated. Last, our study had complete life history information for only salmonids; future studies should incorporate complete life history information for all species.

Our results show that during daytime juvenile salmon are more numerous in epipelagic waters of the AC than the CC region and have the most widespread distribution of any species group in both regions but become a relatively minor component of the catch at night in both regions due to dramatic diel increases in abundance of vertically migrating species. Therefore, interactions of juvenile salmon with associated species are lowest during daytime. Additional study is needed to clarify the nature and extent of diel interactions of juvenile salmon and associated species.

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References

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and Northeastern Pacific. NOAA Technical Report NMFS 66.

Apollonio, S. 1994. The use of ecosystem characteristics in fisheries management. Reviews in Fisheries Science 2(2):157–180.

Armstrong, R. H., and P. C. Winslow. 1968. An incidence of walleye pollock feeding on salmon young. Transactions of the American Fisheries Society 97(2):202–203.

Bailey, K. M., R. C. Francis, and P. R. Stevens. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. California Cooperative Oceanic Fisheries Investigations Report 23:81–98.

Bax, N. J. 1983. Early marine mortality of marked juvenile chum salmon (*Oncorhynchus keta*) released into Hood Canal, Puget Sound, Washington, in 1980. Canadian Journal of Fisheries and Aquatic Sciences 40:426–435.

Beacham, T. D. 1991. The marine survival of salmon program. Program outline and summaries for 1989/90. Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, British Columbia.

Beamish, R. J., and D. R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Sciences 50(5):1002–1016.

Beamish, R. J., D. McCaughran, J. R. King, R. M. Sweeting, and G. A. McFarlane. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. North American Journal of Fisheries Management 20:369–375.

Beamish, R. J., and G. A. McFarlane. 1999. Applying ecosystem management to fisheries in the Strait of Georgia. Pages 637–664 *in* Ecosystem approaches for fisheries management. University of Alaska Sea Grant College Program, AK-SG-99–01, Fairbanks.

Beamish, R. J., G. A. McFarlane, and J. Schweigert. 2001. Is the production of coho salmon in the Strait of Georgia linked to the production of Pacific herring? Pages 37–50 *in* Herring: expectations for a new millennium. University of Alaska, Sea Grant College Program, AK-SG-01–04, Fairbanks.

Beamish, R. J., and C. M. Neville. 1995. Pacific salmon and Pacific herring mortalities in the Frazer River plume caused by river lamprey (*Lampetra ayresii*). Canadian Journal of Fisheries and Aquatic Sciences 52(2):644–650.

Beamish, R. J., B. L. Thomson, and G. A. McFarlane. 1992. Spiny dogfish predation on Chinook and coho salmon and the potential effects on hatchery-produced salmon. Transactions of the American Fisheries Society 121:444–445.

Blaxter, J. H. S., and F. G. T. Holliday. 1963. The behaviour and physiology of herring and other clupeids. Advances in Marine Biology 1:261–393.

Bottom, D. L., B. E. Riddell, and J. A. Lichatowich. 2006. The estuary, plume, and marine environments. Pages 507–569 *in* R. N. Williams, editor. Return to the river, restoring salmon to the Columbia River. Elsevier Academic Press, Massachusetts.

Brodeur, R. D., E. A. Daly, M. V. Sturdevant, T. W. Miller, J. H. Moss, M. Thiess, M. Trudel, L. A. Weitkamp, J. Armstrong, and E. C. Norton. 2007. Regional comparisons of juvenile salmon feeding in coastal marine waters off the west coast of North America. Pages 183–203 *in* C. B. Grimes, R. D. Brodeur, L. J. Haldorson, and S. M. McKinnell, editors. The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland.

Brodeur, R. D., J. P. Fisher, R. L. Emmett, C. A. Morgan, and E. Casillas. 2005. Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. Marine Ecology Progress Series 298:41–57.

Brodeur, R. D., J. P. Fisher, D. J. Teel, R. L. Emmett, E. Casillas, and T. W. Miller. 2004. Juvenile salmonid distribution, growth, condition, origin, environmental and species associations in the northern California Current. Fishery Bulletin 102:25–46.

Brodeur, R. D., W. G. Pearcy, and S. Ralston. 2003. Abundance and distribution patterns of nekton and micronekton in the northern California Current transition zone. Journal of Oceanography 59:515–534.

Dufrêne, M., and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67:345–366.

Emmett, R. L., and R. D. Brodeur. 2000. The relationship between recent changes in the pelagic nekton community off Oregon and Washington and physical oceanographic conditions. Pages 11–20 *in* J. H. Helle, Y. Ishida, D. Noakes, and V. Radchenko, editors. Recent changes in ocean production of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin 2.

Emmett, R. L., R. D. Brodeur, and P. M. Orton. 2004. The vertical distribution of juvenile salmon (*Oncorhynchus* spp.) and associated fishes in the Columbia River plume. Fisheries Oceanography 13:392–402.

Emmett, R. L., G. K. Krutzikowsky, and P. Bentley. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998–2003: relationship to oceanographic conditions, forage fishes, and juvenile salmonids. Progress in Oceanography 68:1–26.

Healey, M. C. 1983. Coastwide distribution and ocean migration patterns of ocean- and stream-type Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Field Naturalist 97:427–433.

Jay, C. V. 1996. Distribution of bottom-trawl fish assemblages over the continental shelf and upper slope of the U.S. west coast, 1977–1992. Canadian Journal of Fisheries and Aquatic Sciences 53:1002–1016.

Kruskal, J. B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29:127.

Krutzikowsky, G. K., and R. L. Emmett. 2005. Diel differences in surface trawl catches off Oregon and Washington. Fisheries Research 71:365–371.

Larkin, P. A. 1977. Pacific salmon. Pages 156–186 *in* J. A. Gulland, editor. Fish population dynamics. J. Wiley & Sons, New York.

Legendre, P., and L. Legendre. 1998. Numerical ecology. Second English edition. Elsevier B.V., Amsterdam.

Mais, K. F. 1974. Pelagic fish surveys in the California Current. California Department of Fish and Game Fish Bulletin 162.

Makris, N. C., P. Ratilal, D. T. Symonds, S. Jagannathan, S. Lee, and R. W. Nero. 2006. Fish population and behavior revealed by instantaneous continental shelf-scale imaging. Science 311:660–663.

McCune, B., and J. B. Grace. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon.

McCune, B., and M. J. Mefford. 1999. Multivariate analysis of ecological data, version 4.28. MjM Software Design, Gleneden Beach, Oregon.

McFarlane, G. A., and J. R. King. 2003. Migration patterns of spiny dogfish (*Squalus acanthias*) in the North Pacific Ocean. Fishery Bulletin 101:358–367.

Morris, J. F. T., M. Trudel, M. E. Thiess, R. M. Sweeting, J. Fisher, S. A. Hinton, E. A. Ferguson, J. A. Orsi, E. V. Farley, Jr., and D. W. Welch. 2007. Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. Pages 81–104 *in* C. B. Grimes, R. D. Brodeur, L. J. Haldorson, and S. M. McKinnell, editors. The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland.

Mueter, F. J., and B. L. Norcross. 2002. Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska. Fishery Bulletin 100:559–581.

Mundy, P. R., and A. Hollowed. 2005. Fish and shellfish. Pages 81–97 *in* P. R. Mundy, editor. The Gulf of Alaska: biology and oceanography. University of Alaska, Alaska Sea Grant College Program, Fairbanks.

Mundy, P. R., and P. Olsson. 2005. Climate and weather. Pages 25–34 *in* P. R. Mundy, editor. The Gulf of Alaska: biology and oceanography. University of Alaska, Alaska Sea Grant College Program, Fairbanks.

Murphy, J. M., A. L. J. Brase, and J. A. Orsi. 1997. Survey of juvenile Pacific salmon in the northern region of southeastern Alaska, May–October 1997. NOAA Technical Memorandum NMFS-AFSC-105.

Myers, K. W., R. V. Walker, H. R. Carlson, and J. H. Helle. 2000. Synthesis and review of U.S. research on the physical and biological factors affecting ocean production of salmon. Pages 1–9 *in* J. H. Helle, Y. Ishida, D. Noakes, and V. Radchenko, editors. Recent changes in ocean production of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin 2.

NOAA. 2005. New priorities for the 21st century–NOAA's Strategic Plan, updated for FY 2006–FY 2011. Available: http://www.spo.noaa.gov/ (December 2005).

NRC (National Research Council). 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington D.C.

Orsi, J. A., and A. C. Wertheimer. 1995. Marine vertical distribution of juvenile Chinook and coho salmon in southeastern Alaska. Transactions of the American Fisheries Society 124:159–169.

Orsi, J. A., and H. W. Jaenicke. 1996. Marine distribution and origin of prerecruit chinook salmon, *Oncorhynchus tshawytscha*, in southeastern Alaska. Fishery Bulletin 94:482–497.

Orsi, J. A., M. V. Sturdevant, J. M. Murphy, D. G. Mortensen, and B. L. Wing. 2000. Seasonal habitat use and early marine ecology of juvenile Pacific salmon in southeastern Alaska. Pages 111–122 *in* J. H. Helle, Y. Ishida, D. Noakes, and V. Radchenko, editors. Recent changes in ocean production of Pacific salmon. North Pacific Anadromous Fish Commission Bulletin 2.

Orsi, J. A., A. C. Wertheimer, M. V. Sturdevant, E. A. Fergusson, D. G. Mortensen, and B. L. Wing. 2004. Juvenile chum salmon consumption of zooplankton in marine waters of southeastern Alaska: a bioenergetics approach to implications of hatchery stock interactions. Reviews in Fish Biology and Fisheries 14(3):335–359.

Parker R. R. 1962. A concept of the dynamics of pink salmon populations. Pages 203–211 *in* N. J. Wilimovsky, editor. Symposium on pink salmon. H. R. MacMillian Lectures in Fisheries. University of British Columbia, Institute of Fisheries, Vancouver.

Pearcy, W. G. 1992. Ocean ecology of north Pacific salmonids. Washington Sea Grant Program, Seattle.

Royer, T. C. 2005. Hydrographic responses at a coastal site in the northern Gulf of Alaska to seasonal and interannual forcing. Deep-Sea Research II 52:267–288.

Scheuerell, M. D., and J. G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 14(6):448–457.

Schoonmaker, P. K., T. Gresh, J. Lichatowich, and H. D. Radtke. 2003. Past and present Pacific salmon abundance: bioregional estimates for key life history stages. Pages 33–40 *in* J. G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Suchman, C. L., and R. D. Brodeur. 2005. Abundance and distribution of large medusae in surface waters of the northern California Current. Deep-Sea Research II 52:51–72.

von Szalay, P. G. 2003. The feasibility of reducing the variance of fish relative abundance estimates by integrating CPUE data from tow demersal trawl surveys in the Gulf of Alaska. Alaska Fishery Research Bulletin 10(1):1–13.

Wardle, C. S. 1986. Fish behaviour and fishing gear. Pages 463–495 *in* T. J. Pitcher, editor. The behavior of teleost fishes. Croom Helm, London and Sydney.

Ware, D. M., and G. A. McFarlane. 1989. Fisheries production domains in the northeast Pacific

Ocean. Pages 359–379 *in* R. J. Beamish, and G. A. McFarlane, editors. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Canadian Special Publication of Fisheries and Aquatic Sciences 108.

Ware, D. M., and R. E. Thomson. 2005. Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific. Science 308:1280–1284.

Weingartner, T. J., S. L. Danielson, and T. C. Royer. 2005. Freshwater variability and predictability in the Alaska Coastal Current. Deep-Sea Research II 52:169–191.

Wertheimer, A. C., and F. P. Thrower. 2007. Mortality rates of chum salmon during their early marine residency. Pages 233–247 *in* C. B. Grimes, R. D. Brodeur, L. J. Haldorson, and S. M. McKinnell, editors. The ecology of juvenile salmon in the northeast Pacific Ocean: regional comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland.

Willette, T. M., R. T. Cooney, V. Patrick, D. M. Mason, G. L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography 10:77–87.

Appendix A. Total day catches of neritic fishes by species in coastal and inshore localities of the California Current and the Alaska Current along the west coast of North America, spring–summer (SS, May–July) and summer–fall (SF, August–October) 2000–2004.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Agonidae	*Agonopsis vulsa*	Northern spearnose poacher	2	2	350	6	0	0	0	0
	Podothecus accipenserinus	Sturgeon poacher	1	27	0	0	0	1	0	2
Alopiidae	*Alopias vulpinus*	Thresher shark	3	5	0	0	0	0	0	0
Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance	658	4	237	1,105	410	1,824	1	0
Anarhichadidae	*Anarrhichthys ocellatus*	Wolf-eel	75	36	129	10	7	5	9	5
Anoplopomatidae	*Anoplopoma fimbria*	Sablefish	744	63	28	0	137	162	0	0
Atherinidae	*Atherinops affinis*	Topsmelt			1					
	Atherinopsis californiensis	Jacksmelt	6,427	9,529	611	0	0	0	0	0
	Leuresthes tenuis	California grunion		4						
Batrachoididae	*Porichthys notatus*	Plainfin midshipman	1	2	2	2	0	0	0	0
Bothidae	*Citharichthys sordidus*	Pacific sanddab	100	47	0	0	0	0	0	0
	C. stigmaeus	Speckled sanddab	34	6	0	0	0	0	0	0
Bramidae	*Brama japonica*	Pacific pomfret	0	0	0	0	7	26	0	0
Carangidae	*Trachurus symmetricus*	Jack mackerel	1,193	1,231	0	0	0	0	0	0
Carcharhinidae	*Prionace glauca*	Blue shark	62	32	0	0	0	0	0	0
Centrolophidae	*Icichthys lockingtoni*	Medusafish	66	328	0	0	0	0	0	0
Chimaeridae	*Hydrolagus colliei*	Spotted ratfish	0	0	0	1	0	0	0	0
Clupeidae	*Alosa sapidissima*	American shad	49	10	5	0	0	0	0	0
	Clupea pallasii	Pacific herring	214,008	55,882	385,956	266,255	216	4,182	135	70
	Sardinops sagax	Pacific sardine	67,571	169,716	165	1	0	0	0	0
Cottidae	*Hemilepidotus* sp.	Irish lord	2	0	0	0	0	0	0	0

Appendix A. Continued.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Cottidae	*Leptocottus armatus*	Pacific staghorn sculpin	3	3	1	0	0	0	0	0
	Scorpaenichthys marmoratus	Cabezon	12	0	6	0	0	0	0	0
Cyclopteridae	*Aptocyclus ventricosus*	Smooth lumpsucker	0	0	0	0	14	6	7	5
	Eumicrotremus orbis	Pacific spiny lumpsucker	0	1	0	9	1	0	9	9
Embiotocidae	*Amphistichus argenteus*	Barred surfperch	0	0	12	0	0	0	0	0
	Cymatogaster aggregata	Shiner perch	0	10	24	0	0	0	0	0
	Embiotoca jacksoni	Black perch	0	0	3	0	0	0	0	0
	E. lateralis	Striped seaperch	0	0	2	0	0	0	0	0
	Hyperprosopon argenteum	Walleye surfperch	0	0	15	0	0	0	0	0
	H. ellipticum	Silver surfperch	0	0	1	0	0	0	0	0
	Phanerodon furcatus	White surfperch	0	0	15	0	0		0	0
Engraulidae	*Engraulis mordax*	Northern anchovy	70,660	15,680	59,102	11	0	0	0	0
Gadidae	*Gadus macrocephalus*	Pacific cod	29	0	1	1	34	21	10	0
	Microgadus proximus	Pacific tomcod	565	92	1	0	113	2	0	0
	Theragra chalcogramma	Walleye pollock	206	0	49	40	1,207	1,543	4,621	12,153
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback	1	12	381	30,124	3	5,001	0	0
Hemitripteridae	*Blepsias bilobus*	Crested sculpin					7	19	203	232
	B. cirrhosus	Silverspotted sculpin	0	0	2	0	1	0	1	0
	Hemitripterus bolini	Bigmouth sculpin	0	0	0	0	0	0	1	0

Appendix A. Continued.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Hemitripteridae	*Nautichthys oculofasciatus*	Sailfin sculpin	1	0	1	0	0	0	0	0
Hexagrammidae	*Hexagrammos decagrammus*	Kelp greenling	9	0	105	1	0	0	0	0
	H. stelleri	Whitespotted greenling	0	0	2	0	0	0	0	1
	Ophiodon elongatus	Lingcod	135	2	9	2	51	0	1	0
	Oxylebius pictus	Painted greenling	6	0	2	0	0	0	0	0
	Pleurogrammus monopterygius	Atka mackerel	0	0	0	0	5	1	0	0
Icosteidae	*Icosteus aenigmaticus*	Ragfish	1	5	0	0	0	0	0	0
	Isopsetta isolepis	Butter sole	0	1						
Lamnidae	*Lamna ditropis*	Salmon shark	0	1	0	0	4	6	4	3
Liparidae	*Liparis florae*	Tidepool snailfish	1	0	0	1	0	0	0	0
	L. greeni	Lobefin snailfish	0	0	0	1	0	0	0	0
	Liparis mucosus	Slimy snailfish	0	0	0	3	0	0	0	0
Merlucciidae	*Merluccius productus*	Pacific hake	109	11	97	211	0	0	0	1
Molidae	*Mola mola*	Ocean sunfish	28	36	0	0	0	0	0	0
Myctophidae	*Stenobrachius leucopsarus*	Northern lampfish	0	1	0	0	0	0	0	0
Myliobatidae	*Myliobatis californica*	Bat ray	3	3	16	0	0	0	0	0
Myxinidae	*Eptatretus stoutii*	Pacific hagfish	0	0	17	0	0	0	0	0
Osmeridae	*Allosmerus elongatus*	Whitebait smelt	4,184	438	3	112	0	0	0	0
	Hypomesus pretiosus	Surf smelt	6,326	1,833	11	0	1	4	0	0

Appendix A. Continued.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Osmeridae	*Mallotus villosus*	Capelin	7	0	0	0	3,155	4,633	3	66
	Spirinchus starksi	Night smelt		2	0	0	0	0	0	0
	S. thaleichthys	Longfin smelt	9	2	0	0	0	0	0	0
	Thaleichthys pacificus	Eulachon	41	0	1	49	2	0	0	2
Petromyzontidae	*Lampetra ayresii*	River lamprey	1	0	477	59	0	0	0	0
	L. tridentata	Pacific lamprey	3	2	1	0	0	0	0	0
Pholidae	*Pholis laeta*	Crescent gunnel	0	0	0	1	0	0	0	0
Pleuronectidae	*Atheresthes stomias*	Arrowtooth flounder	1	0	0	0	0	0	0	0
	Glyptocephalus zachirus	Rex sole	0	0	0	0	0	1	0	0
	Hippoglossus stenolepis	Pacific halibut	0	1	0	0	0	0	0	0
	Lepidopsetta bilineata	Rock sole	0	1	0	0	0	0	0	0
	Microstomus pacificus	Dover sole	0	0	1	0	0	0	0	0
	Parophrys vetulus	English sole	1	1	0	1	0	0	0	0
	Platichthys stellatus	Starry flounder	43	26	39	11	0	0	1	0
	Pleuronichthys coenosus	C-O turbot (sole)	0	1	0	0	0	0	0	0
	P. decurrens	Curlfin sole	3	0	0	0	0	0	0	0
	Psettichthys melanostictus	Sand sole	6	0	0	0	0	0	0	0
Psychrolutidae	*Psychrolutes paradoxus*	Tadpole sculpin	0	0	5	0	0	0	0	0
	P. sigalutes	Soft sculpin	3	0	5	0	6	37	7	1,083

Appendix A. Continued.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Ptilichthyidae	*Ptilichthys goodei*	Quillfish	0	0	21	3	0	0	0	0
Rajidae	*Raja binoculata*	Big skate	3	5	0	0	0	0	0	0
	R. rhina	Longnose skate	0	1	0	0	0	0	0	0
Rhamphocottidae	*Rhamphocottus richardsonii*	Grunt sculpin	0	0	0	0	0	1	0	0
Salmonidae	*Oncorhynchus clarkii*	Cutthroat trout	21	11	0	0	0	0	0	0
	O. gorbuscha	Pink salmon	694	1,387	14,296	9,728	10,812	7,647	12,443	2,594
	O. keta	Chum salmon	1,666	442	26,360	18,926	4,300	2,686	11,516	849
	O. kisutch	Coho salmon	3,529	1,896	12,783	6,871	1,696	1,480	1,311	384
	O. mykiss	Steelhead	109	24	2	0	4	0	0	0
	O. nerka	Sockeye salmon	1,010	208	1,832	2,892	2,246	3,875	1,378	370
	O. tshawytscha	Chinook salmon	3,787	2,014	9,638	5,274	187	95	175	203
	Salmo salar	Atlantic salmon	0	1	0	0	0	0	0	0
	Salvelinus malma	Dolly Varden	0	0	0	0	0	1	0	0
Sciaenidae	*Atractoscion nobilis*	White seabass	0	2	0	0	0	0	0	0
	Genyonemus lineatus	White croaker	61	75	0	0	0	0	0	0
	Seriphus politus	Queenfish	0	0	1	0	0	0	0	0
Scomberesocidae	*Cololabis saira*	Pacific saury	122	2,477	0	0	0	9	0	0
Scombridae	*Scomber japonicus*	Pacific chub mackerel	69	105	0	0	0	0	0	0
	Thunnus alalunga	Albacore	1	0	0	0	0	0	0	0
Scorpaenidae	*Sebastes alutus*	Pacific ocean perch	42	0	0	0	0	0	0	0
	S. brevispinis	Silvergray rockfish	17	0	0	0	0	0	0	0
	S. ciliatus	Dusky rockfish	0	0	0	0	0	0	1	0
	S. crameri	Darkblotched rockfish	143	0	0	0	0	0	0	0
	S. entomelas	Widow rockfish	13	0	0	0	0	0	0	0

Appendix A. Continued.

			California Current				Alaska Current			
			Coastal		Inshore		Coastal		Inshore	
Family	Genus species	Common name	SS	SF	SS	SF	SS	SF	SS	SF
Scorpaenidae	*Sebastes flavidus*	Yellowtail rockfish	361	11	0	0	0	0	0	0
	S. jordani	Shortbelly rockfish	6	1	0	0	0	0	0	0
	S. melanops	Black rockfish	26	6	0	0	5	1	0	0
	S. mystinus	Blue rockfish	4	0	0	0	0	0	0	0
	S. paucispinis	Bocaccio	10	0	0	0	0	0	0	0
	S. pinniger	Canary rockfish	50	0	0	3	0	0	0	0
	S. saxicola	Stripetail rockfish	6	0	0	0	0	0	0	0
Sphyraenidae	*Sphyraena argentea*	Pacific barracuda	0	1	0	0	0	0	0	0
Squalidae	*Squalus acanthias*	Spiny dogfish	9,998	1,442	2,927	1,692	7,289	561	0	0
Stromateidae	*Peprilus simillimus*	Pacific pompano	250	261	963	0	0	0	0	0
Syngnathidae	*Syngnathus leptorhynchus*	Bay pipefish	0	0	10	69	0	0	0	0
Torpedinidae	*Torpedo californica*	Pacific electric ray	7	7	2	0	0	0	0	0
Trachipteridae	*Trachipterus altivelis*	King-of-the-salmon	1	10	0	0	0	0	0	0
Triakidae	*Galeorhinus galeus*	Tope	26	1	0	0	0	0	0	0
Trichodontidae	*Trichodon trichodon*	Pacific sandfish	44	3	33	8	74	8,076	9	2
Zaproridae	*Zaprora silenus*	Prowfish	7	4	0	0	130	62	59	44
		Total fish catch	395,476	265,484	516,759	343,483	32,124	41,968	31,905	18,078
		Fish families total (52)	40	42	29	23	18	22	15	14
		Fish species total (118)	76	66	55	34	30	30	23	20